SELECTED SOIL PROPERTIES AND COMPOSITION OF ASSOCIATED ROOTS IN EASTERN PANAMA

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INTRODUCTION

In 1967, the University of Florida's Center for Tropical Agriculture initiated agricultural ecology field studies in eastern Panama and northwestern Colombia. These studies were a part of the Battelle Memorial Institute Columbus Laboratories, Bioenvironmental Safety Feasibility Study for a nuclear-excavated, sea level canal across the Isthmus of Panama authorized under Public Law 88-609, 88th Congress.

The major objectives of this program were to predict radiation exposure doses from external and internal sources that would be imposed on the biota (including man) by the proposed nuclear excavations. For these predictions, a conceptual model consisting of the important compartments and pathways involved in the cycling of nuclides through the agriculture food chain to man was visualized (50).

Two pertinent problems were recognized. One was how will the radionuclides behave chemically in the soil. The other was will these nuclides be available for uptake by plants to the food webs. Information concerning the chemical and mineralogical properties of these soils was required to assist the plant ecologist in predicting concentrations of radionuclides to be expected in plants, which is the first step in many food webs.

Many of the most important chemical and physical properties of the soil, which determine passage through the soil and availability

of radionuclides for uptake are dependent to a very large degree on the minerals constituting the clay fraction (<2 μ). Thus it is imperative, for the prediction of radiation exposure doses, that the types of clay minerals and some of their basic properties be studied. Gamble et al. (50) have noted that little is known of the elemental composition of the food plants and even less is known about the soils of this area.

The principal objectives of this study were to determine some of the important physical and chemical properties of the soil clays from agricultural areas located near a proposed canal site (route 17) in eastern Panama. A secondary objective was to study the root, leaf and adjacent soil analysis of food plants and secondary vegetation from these same or adjacent locations to determine the concentration of mineral elements and evaluate relationships between the soil compartment and root and leaf compartments.

LITERATURE REVIEW

Darien Province in Panama

Location

Darien Province is bounded by Colombia on the east, Panama Province on the west, the Atlantic Ocean on the north, and the Pacific Ocean on the south.

Topography

Panama is predominantly a country of low to medium elevation. The major features encountered in the relief along proposed route 17 are the Cordillera de San Blas. The San Blas range creates a continental divide parallel to the Caribbean and is separated from it by a narrow coastal plain which occasionally disappears where the hills extend down to the sea (50). Most of the subtropical belt is comprised of rough topography, with only very limited areas of flat or gently sloping lands located in the valleys or on the tops of the wider ridges. The lower tropical belt which covers the major part of Panama is predominantly hilly and broken with some large expanses of river-valley areas located in the Darien Province (61).

Climate and Weather

Route 17, proposed as a study area in Darien Province, is mostly tropical rainland with both a wet season and a dry season. Only a few peaks above 4,000 feet are cool enough to be called temperate.

D urna var at ons are re ative y arge,ranging from 4 to 6C at some locations Th s var ation produces considerable ear y-morn ng cooling, often with associated low clouds and ground fog (9, 6).

Precip tat on s essent.al y orographic on the Car'bbean coast where winds from the northeast and east br ng mo:sture-laden air to the land. The highest annual prec pitation occurs n the lower part of the lower montane or the upper part of the subtropical belt. On the Pacific side, the precipitation is predominantly convect onal, occurring during the rainy season when the be t of doldrums has moved north from South America. However, there appears to be a so a strong nfluence of w nds from the southwest. In genera , the whole Car b-bean side s mo:st to wet whereas the Pacific side is broken nto mo:st or dry subreg ons (6). This difference is illustrated by Cristobal, at the Caribbean terminus of the Panama Cana , and Balboa Heights, at the Pac fic terminus where long range weather stat ons are located. Cristobal receives 3,250 mm of prec pitation per year, with a maximum of about 570 mm in November, there, the dry season usua y extends from January through Apr l Balboa Heights, on the Pacific side, records 1,760 mm annually, usua y with a but about 150 mm falling between March and mid-December (9).

Plant Eco.ogy

The greater part of the owland areas fa l according to Ho dridge (60) and Holdridge and Budowski (61) in the classification of trop cal mo,st Forest formation having a mean annual temperature of 24C or above and an average annua rainfall of 2,000 mm or more. The upper reaches of the Rio Sabana and Rio Chucunaque are ocated in the area tranversed by the proposed cana route 17. These areas having approx-

imate y 2,000 mm of ra nfall, fa into a distinct trans t on zone between trop cal moist and dry forest. Ra nfa l increases along the Pacific coast to the south and towards the Colomblan border and the San Blas. Th s g ves rise to typical mo st forest. Cons derab e areas of the subtropica. wet forest and sma ler areas of the lower montane wet forest are encountered with increasing elevat on (60, 6)

Geology

The geology of the proposed site is shown In F g. 1. Generally, in the Pacif c watershed, the route transverses a series of sed mentary outcrops composed princ pally of calcareous sha es, sandstones, and Timestones Tertiary in age. North of La Palma, across the Tu ra estuary, basaltic outcrops intrude into the dark shales. The geo- og c formational units are n approximate a lgrment with the Isthmus. The Caribbean side has an igneous basement complex. Narrow sandy beach deposits are found along both coasts Interior geologica for- mat ons are composed of calcareous sandstones, sha es, and fossi Imestones Tertiary in age (9, 50, 123). The Jnited States Corps of Eng neers have rev'ewed the geo ogy of eastern Panama in detail (123).

Soils

Soil formation in Darien Prov nce s inf uenced by h gh temper- atures and rainfall which resu t In heavy leaching and ateriza tion The nland forest soils have been reported to have low humus in the surface soi s, due to rapid oxidation of organic matter, and deep, well-oxidized subsoi s (9).

Gamble et al. (50, 51) recognized two orders which were Entisols and Oxisols and three suborders of Entisols. The suborders were

Fig --Generalized geologic map of route 7 area, Panama

Source: U.S. Corps of Engineers, 1923

Psamments, Aquents, Orthents, and a rol ng phase of Orthents (F.g. 2). The above soi s were expressed n genera terms, with the exception of beach sands, by Mart ni et a . (85) as moist areas, a luv al soils, upland, nonlatasol and latasol, Beach sands have been described by Wheeler (129).

Systems of Agriculture

The systems of agriculture in this area have been described in detail by Gamble (48) and Gamble et al (50) They descr bed sh fting agriculture as the in tial fell ng and burning of most of the trees fol owed by a crop with no cultivat on of the soil, After crop production, this land reverts back to jungle. However, they reported that a r verine system was fol owed wherever the rivers had sufficiently arge bottom river terraces to support a garden following deposition of sediment from the rainy-season flooding In th s system, rice was grown n the ow areas and corn or other food crops on the higher and. Also, they noted subsistence-type gardens which were cult vated close to the houses with a large variety of food crops for home use. Also, they described a p antation system which usually consisted of large areas of banana and lesser sized acreages of coconut and avocado. Whereas, ivestock operations, usually conf ned to the Pacific side, consist ng primari y of catt e, poultry, and swine were observed.

Components of Soil Clay and Their Identification

Nature of Soi Clay

The clay fraction of soils cons sts of both crystalline minera s that can be dent.fied by X-ray d ffraction and other norgan c co oids that do not g ve X-ray diffraction patterns and are termed

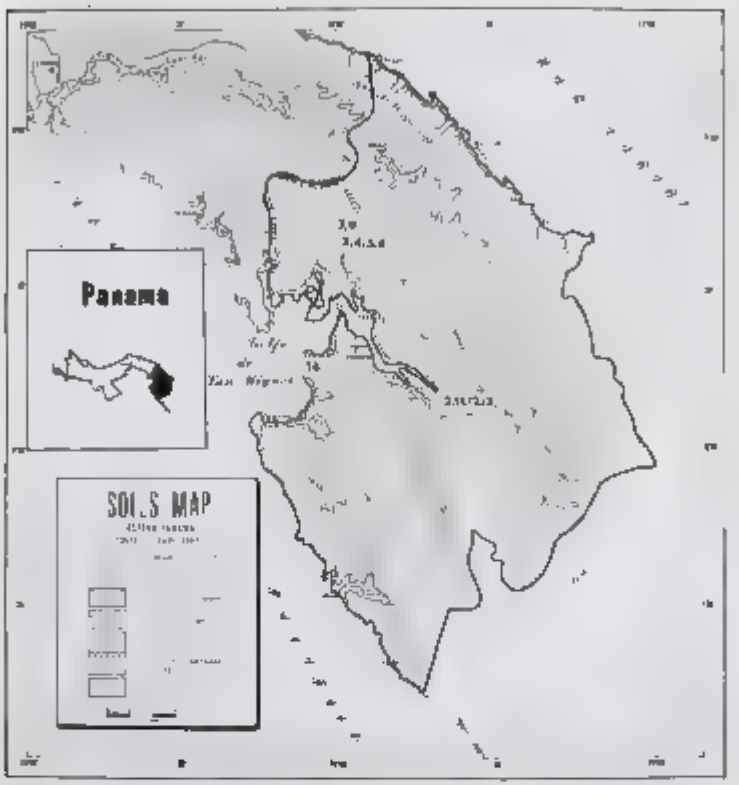

Fig. 2.--General soils map of Darien province located in eastern Panama. The inset numbers refer to locations for root, soil, and plant samples where 1 is Yaviza, 2 is Veziva, 3 is Trocha, 4 is Santa Fe, 5 is Rio Lara, 6 is Nuno, 7 is Rio Sabana, 8 is Santa Fe, 9 is Santa Fe, 10 is Rio Chucunaque, 11 is Rio Grande, 12 is Pinogana, and 13 is Patino

Source: Original map by Gamble and Ah Chu (50).

amorphous or X-amorphous Ear y workers be ieved the clay fraction to be amorphous and attributed the phenomenon of cation-exchange to colloidal oxides. After the demonstrations by Hendricks and Fry (58) and Kelley et al. (72) that soil c ays were crystalline mineral components, with h gh cation exchange capacity (CEC) the earlier view of amorphous co o ds was largely abandoned. Most of the emphasis has been p aced on X-ray diffraction analysis n investigations of the structure, properties, and abundance of soil clay minerals. Although many workers have found evidence for presence of amorphous c ays in so ls, there is re atively ittle information regarding the nature, extent, or properties of such components of the clay fraction. The amorphous soil mater a s can be classified as allophane" or allophane- ike", other amorphous aluminosi cates, free iron oxides, free alumina, manganese oxides, and hydrous silica.

A.lophan.c Propert es

The term 'a ophane has been used for a wide var ety of non-crysta ine colloidal minera substances that are common constituents of so s (86). Aom ne and Yosh naga (5) assoc ated allophane with humus occurring In surface soils as a product of weathering of volcan c ash Allophane .s a genera term for amorphous aluminosi icate ge s of a w de range in composition. The SiO_2 Al_2O_3 mo e ratio falls in the range of 0.5 to 1.5 or 2.0 The composit on includes structural H_2O and OH, also, iron oxides may be occluded n al ophane (65, 67, 68) D fferential thermal analys s (DTA) Indicates surface-soil allophane by a carbon-burn ng exotherm in the range of 450 to 550C as well as a low temperature endotherm at 160C (39, 65)

Delta cation-exchange capac.ty of allophane

Aom ne and Jackson (3) noted that the CEC of allophane measured at pH 7.0 var.ed a great dea accord ng to the pH of reagents employed in the c ay-dispersion process. They noted that the c ay fraction when separated in an alkal ne medium at pH 10.7 gave CEC as h gh as 150 meq per 00 g of c ay, whereas the c.ay fraction from the same soil originally separated with an acid dispersion medium had an exchange capacity only about one-third that of the sample rece ving a kal ne dispersion. They found the CEC of the acid-dispersed sample equa ed that of the alka ine c ay upon treatment with a mild a kal ne buffer They considered th s property as d agnostic for allophane.

Or.gin of charge of allophane

Accord ng to V llers and Jackson (25) the negative charge of al ophane resulted from isomorphous substitution of Al for SI in tetrahedral coord.nation with oxygen, which is analogous to that n crysta ine layer silicates. They noted that subst tution of an A for Si, in each four S atoms, resulted in a "permutite" structure which has a composit on approaching $NaSi_3A O_6(OH)_4$, of which the Na Is exchangeable and the CEC charge Is 335 meq per 100 g as a maximum. t was their postulat on that hydroxy Al with a coordination number of six may block some of the tetrahedral negative charge, w th either protonat on or deprotonation account ng for the observed hysters s of the CEC. They attributed this CEC of the colloid to electrolytic properties from a h gh specific surface of $Al(OH)_2^+$ and an assoc ation of the Al surface with other minerals possessing a net negative charge.

Occurrence of a.lophane

DeMumbrum and Chesters (32), util zing a fractionation procedure

based on acid d spersion, concentrated inorganic amorphous colloidal mater al from several soils. They found these allophanes were metallic silicates, largely hydrous-Al sil cates, and hydrous-Al compounds which they considered residues of chem ca weather ng w th n the so l profiles stud'ed. In the B and C horizons examined, they found micro-crystall ne particles of halloys te wh ch were shown to be intimately mixed w th the amorphous residues. Aomine and Yosh naga (5) showed by DTA that a ophane n some wel -dra ned so ls derived from vo canic ash in Japan have endothermic peaks at 200C and from 400 to 600C. The CEC determined at pH 7.0 var ed from 23.3 to 57.3 meq per 100 g. Wada (127) found that the CEC of a lophane doub ed n al cases from pH 4.0 to 7.0, whereas an halloysite increased only 2 meq per 100 g over the same range. B rrell and Fieldes (2) found that deferration of the Whenuapi clay fraction resulted in a very much reduced content of bound H_2O as found by DTA at the low-temperature endotherm They reported that the h gh-temperature exotherms d sappeared upon defer-ration. The SiO_2 Al_2O_3 mo e ratio for th's mater'al was 1 2 to 1 52. Patterson (99) reported al ophane in some soils of Hawa with an Al_2O_3 SiO_2 mole ratio of exactly 2.0 and with a DTA endotherm that extended from 180-300C.

Types of a..ophane

Jackson (68) classified stable allophane as that which s dis-solved on y slightly either n HCl at pH 3.5 or in a 2% solution of Na_2CO_3 in contrast to unstable a lophane which was solub e n d lute acids and alkalies. The more unstab e allophane, he concluded, was formed qu ckly by weathering of permeable volcanic ash, stable al o-phane was thought to be a weathering rel c of halloys te and kaolinite.

B rrel and Fieldes (2) reported that, in New Zealand soils, dispersion of soils contain ng allophane appears to be practicable only f free sesquioxide content is low and the medium s kept at least at pH 10.

F eldes (38) distingu shed between 'allophane B" where amorphous s ica was discrete and the particles were very fine and "allophane A" where s lica and alum na were randomly combined and the partic e s ze was larger than for allophane B. He reported that, with increasing age of the c ay derived from volcan c ash, the sequence was from a ophane B, to allophane A, to metahalloysite, and f nally to kaolinite.

Yoshinaga and Aom ne (35) separated a thread- ike crystall ne fraction cal ed Imogolite, from a soil dom nated by allophane Aomine and M yauch (4) divided imogol te further into subspecies A and B which they found could be detected with X-ray diffraction. They concluded that mogolite A has no characteristic endotherm c DTA pattern whereas imogolite B has an endothermic peak at about 420C. These forms of allophane they regarded as representing d fferent weathering stages in wh ch the sequence is as fol ows volcanic ash, amorphous si ica and alumina, allophane B allophane A, Imogol te A, imogolite B, and kaolinites (4, 69). Tan (1 9) study ng andoso s or andepts from tropical west Java found the properties varied somewhat,depending on the pedogenic age. He noted that the younger soil had an AC profile that contained amorphous materia tentatively called proallophane mixed with pedogenic intergradient verm cul te. The SiO_2 Al_2O_3 mole ratio, he found, was near y 10 in the surface horizons. The o der soils, in h s study, had thicker AC or ABC profiles w th the clay fraction dominated by a lophane.

Mejia et al (92), studying soils derived from volcanic ash in the Colombian Andes, found allophane to predominate. They suggested transformation of allophane into halloysite from data obtained by infrared analysis.

Other Amorphous Aluminosilicates

Jackson (68) stated that amorphous and finely divided crystalline compounds are hydrous. Amorphous aluminosilicates of soils, which he classified as non-crystalline, gel-like compounds contained mainly Al, Si, O, and H_2O, along with some, Fe, Mg, OH, and occasionally PO_4. The common presence in soils of various amorphous aluminosilicates that have properties distinct from those of allophane has generally been recognized. Jackson (68) classified such compounds as highly disordered, three-dimensional, sub-crystalline, clay-like, and clay-relic materials, transitional to crystalline clay minerals being destroyed or synthesized by weathering. Glenn and Nash (52), working with reddish-brown lateritic soils from southern Mississippi, found that kaolinite, gibbsite, and amorphous material became prominent in the less than 0.2 micron fraction with the amorphous colloids comprising as much as 40% of this fraction. Gamble et al (49) studying the soils from eastern Panama found that the amorphous material ranged from 4 to 54% of the clay fraction.

Siliceous, amorphous clays

Smithson (115) and Riquer (100) listed opaline as a common form of silica in soils derived from plants. Palagonite, an amorphous Fe-Al silicate (13), has not been studied extensively. McKeague and Cline (86) conducted tests for the adsorption of monosilicic acid and indicated that at least some of the amorphous silica in soils

occurs as coatings on the surface of iron oxides and other substances. The relatively high silica content of soil extracts after treatment with citrate-dithionite for Fe removal indicated amorphous combinations of iron oxide and silica in soils (86). Yuan (136) found that the clay fraction of nine virgin soil profiles was largely composed of amorphous materials both in surface soils and subsoils. He found a relationship existed between the amorphous SiO_2:Al_2O_3 mole ratio in the clay and the degree of pedon development. The large variation in these mole ratios, that he observed, suggested that the clay fraction probably contained large amounts of free oxides in addition to amorphous aluminosilicates. Mitchell and Farmer (93), studying amorphous clay minerals by DTA in some Scottish soil profiles, obtained a distinct endothermic peak between 100 and 200C. Their results showed that while all the clays examined appeared to contain a proportion of hydrated amorphous material, this component is particularly high in clays from the surface horizon. In their clays the mole ratios of silica to alumina showed that, in general, the amorphous material was much more siliceous than allophane in soils derived from volcanic ash.

Aluminous, amorphous clays

Fieldes et al. (40), studying the CEC of some tropical soils of the Cook Islands, found by DTA that the principal exchange materials in these soils were amorphous, hydrous, aluminum oxides. They also artificially prepared amorphous hydrous oxides of aluminum and titanium which had extremely high CEC. DeMumbrum (31), while studying the soil minerals of the Mississippi Coastal Terrace, found about 15% of the clay was an amorphous, aluminous compound having a low SiO_2 Al_2O_3 mole ratio. Patterson (99), in Hawaiian soil, found an amorphous

material which he described as an alumina-silica gel. The composition of this mater a was about 50% Al_2O_3 and 25% S O_2. Th s material gave an endothermic peak at 180C and another peak at 330C indicative of crysta line gibbsite.

Remova. of Amorphous Alum.nosi.icates

The free amorphous silica, free alumina, and large percentages of amorphous comb ned alum.nosi icates, ncluding allophane, were removed by se.ect ve d ssolution with bo ling 0 5 N NaOH as described by Nashimoto and Jackson (55). This method for remova of amorphous materia from so ls has been used extensive y (53, 55, 65, 68, 70)

Crystalline Soil C.ays

Brad ey (20) has stated that the backbone feature of the clay layer s a distinct array of silica tetrahedra surrounded by oxygens and each oxygen is shared, e ther with n a layer by two s icons, or by extra- ayer condensat on, between a silicon and octahedral ions. He noted that the array affords an nf nite net of 6-membered rings which consists of the coplanar bases of tetrahedra. This arrangement, he noted, cons sted of two equa tetrahedral nets, with ap ces fac ng each other, forming a mot f, together with hydroxy ions, which affords octahedral environment to additional metal ions wh ch are mainly Al^{3+}, Mg^{2+}, and Fe^{2+}. The octahedral on-oxygen associations have a so been found to have some unspec'f,ed but esser degree of covalency n the r nature and have more ionic property than do the S,-O associations. Whittig (130) has reported that the crysta line clay structures are characterized by a systemat c and periodic arrangement of atoms in a three-d mens onal array because crystals

are composed of regularly spaced atoms, each crystal forms planes of atoms which are separated by a constant distance. The distance between planes have proven to be characteristic of the crystalline species.

X-Ray Diffraction Analysis of Clays

The fact that the distance between planes of atoms has proven to be characteristic of a clay is utilized in estimation and identification of soil clay minerals by X-ray diffraction. Since Hendricks and Fry (58) and Kelley (71) demonstrated that soil clays contained crystalline mineral components that yielded X-ray diffraction patterns, this method has become a major tool in investigation of soil clay minerals. The nature and properties of X-ray diffraction and its application to soil clays were discussed thoroughly by Jackson (65), Whittig (130), and Bradley (20).

Interlayer Effects

The subject of interlayers has been reviewed comprehensively by Rich (106) who stated, in effect, that interlayering is restricted to the occurrence, formation, and properties of hydroxy-cation systems between the unit layers of phyllosilicates. He reported vermiculites and smectites in soils and sediments are frequently partially interlayered, hydroxy-Al deposits appeared to be the principal component of the nonexchangeable interlayer material. Little evidence has been found for naturally occurring interlayers composed largely of hydroxy-Fe since iron oxides are relatively stable in the soil (106). This was supported by the work of Bohn (15). Occlusions of $Fe(OH)_3$ in positively charged hydroxy-Al interlayers were thought to be more likely than other hydroxy-Fe forms (15, 106). The partial filling of

the interlayer spaces of soil vermiculite with hydroxy-Al groups was shown to influence NH_4^+ fixation by reducing cation exchangeability of the vermiculite structure (103, 104).

Removal of interlayer material

Rich and Cook (107) and Rich (105) observed that treatment of certain clays with a solution consisting of 0.4 N NH_4F + 0.1 N HCl + 1.0 N NH_4Cl permitted detection by X-ray diffraction of dioctahedral mica and dioctahedral vermiculite. They reported that allophane, halloysite, kaolinite, and, in particular, Mg-rich montmorillonite, biotite and vermiculite of clay size were destroyed by the above reagent after 24 to 48 hours of contact at room temperature. Removal of the above clays was also made with a reagent containing 0.2 N NH_4F and heating for an hour at 70C. Rich and Singh (108) noted that another mixed solution containing 0.4 N NH_4F required about two hours for removal of kaolinite at room temperature. Black and Rich (14) employed a chemical kinetic method to study the rate of dissolution of the components of several soil clays by acidified NH_4F. They determined Al and Fe contents in the solution phase, and obtained both the CEC and X-ray diffraction patterns of the residues. They found a reaction time in the reagent that was characteristic for each clay and noted the rate of dissolution of Al and Fe became slower, at this stage all material originally present with a spacing at 14A readily collapsed to 10A upon K saturation. An initial large increase in dissolution indicated that hydroxy-Al and -Fe interlayers were being dissolved from the more resistant vermiculites, this was followed by destruction of kaolinite.

Retention of Polar Liquids

Such important soil properties as water retention and CEC have been shown to be highly correlated with the surface area exposed (96). Dyal and Hendricks (35) determined the specific surface of clays, which had been dried over P_2O_5 by mixing clay and glycol in equal proportions. They noted the rate of ethylene glycol evaporation decreased when all the free glycol was gone and after 6 hours they concluded that the remaining glycol was adsorbed in a monolayer. Bower and Gschwend (17) worked with glycol saturated samples evacuated over dry $CaCl_2$. They used consecutive weighings to find the transition from the faster rate of loss of free glycol to the slower rate of loss of that bound to the surface of the clay. Bower and Goertzen (16), using a mixture of $CaCl_2$ and glycol under a vacuum, found the values for the determination of specific surfaces of soil clays agreed well with values obtained by Dyal and Hendricks (35). Sor and Kemper (116) noted that the removal of ethylene glycol from clays did not affect the basal spacing in X-ray diffraction studies when glycol was removed, until the monolayer was reached, at which point the basal spacing of the clay decreased as further glycol removal took place. Morin and Jacobs (94) found that surface area determined from adsorption of ethylene glycol from the vapor phase by soils and clays in equilibrium compared favorably with previous equilibrium and non-equilibrium methods. Mortland and Kemper (96) provided an extensive review on the retention of polar liquids by clays and the underlying principles involved.

Mehra and Jackson (90) reported that some montmorillonitic fine clay sorbed an excess of glycerol giving erroneously high values for surface area. After subjecting the montmorillonite to a dissolution

step w th 0.5 N NaOH, the specif c surface decreased to the expected value. They attributed this to the removal of poor y crysta l ne mater a s having high specific surfaces. However, Martin (84) found very little difference for ethy ene glyco retention by soil c ays before and after removal of free-iron oxides. MacEwan (82) emphasized that drying hydrated halloysite increased the total surface area of th s m neral to nearly doub e that of the hydrated form. He a.so reported that vermicu ite only adsorbed one layer of glyco mo ecu es n the clay interlayers although it adsorbed two layers of water on these surfaces. McNea (88) noted a decrease in glyco adsorption with temperatures over 40C. R ch (103) noted that treatment of vermiculite with hydroxy-Al solution for eight days reduced the ethylene g ycol retention from 12.4 to 8.9%; the specific surface increased again, he found, after removal of the Al with NaOH. Barnh sel (6) observed that the internal specific surface of montmori lonite and vermicu ite systems decreased rapidly as hydroxy-A was added. Mehra and Jackson (89, 90) have reported the spec fic surface for several other clay minerals.

Differentia. Thermal Analys s of Clays

Barshad (7) has reported that many soil c ay minera s undergo react ons upon heating. The most important reactions of so clays are the evaporat on of imb bed and adsorbed water and loss of structural hydroxy -groups as H_2O. The app ication and interpretat on of DTA patterns of soil c ays are d scussed thoroughly by Jackson (65), Barshad (7), MacKenz e and Bishu (83), F elds (39) Fiske and Carlis e (44), Alexander et al. (2), and Hendricks and A exander (57).

Infrared Analysis of Clays

If infrared radiation of a given frequency strikes a sample whose molecules have a vibrational frequency the same as that of the incident radiation, the molecule absorbs radiant energy, and the energy of the molecule is increased. If the incident frequency differs from the characteristic frequencies of the molecule, the radiation passes through undiminished (80, 102). Lyon (80) has stated, in effect, that the whole essence of mineralogy lies in the subtle chemical substitutions which divide one mineral species from another. He noted it was often minor compositional differences on which final decisions must be based. These differences are often not discernible by X-ray diffraction or only with other dominantly physical observations. Infrared analysis has been treated in detail by several authors (33, 37, 44, 78, 95, 118). Cross (28) has listed several inorganic group frequencies.

Hunt and Turner (64) observed that kaolinite, illite, and montmorillonite were difficult to identify because the distinctive features of their spectra overlapped in the wavelength region from 1,111 to 833 cm^{-1}. They also noted a characteristic double band for quartz at wavelengths of 800 and 781 cm^{-1}. Tuddenham and Lyon (122) also observed this and another distinctive absorption band at 700 cm^{-1}. They also found the absorption bands for quartz increased in intensity as particle size decreased.

Lyon and Tuddenham (81) reported that the absorption at 3,704 cm^{-1} was found only in the kaolin group and such simple structures as brucite. They attributed this observation to O:H stretching frequencies associated with OH, the oxygen and hydrogen atoms being in two symmetrical layers in the brucite layer. They reported that absorption

at 4,819 cm⁻ was common to all m cas and 3- ayer mInera s Serratosa et a . (11) found four absorption bands for kao in te at 3,695, 3,670, 3,650, and 3,620 cm^{-1}. The band at 3,695 cm^{-1} ncreased in intens ty w th increasing ang es of incidence and apparently corresponds to hydroxyl bands in a direction near y normal .o the surface. The 3,620 cm^{-1} band was assigned to hydroxyl groups directed to the unoccup ed octahedral posit on The other absorpt on bands at 3,670 and 3,650 cm⁻ , they concluded, corresponded to OH wh ch part cipated n hydrogen bonding between layers. Farmer (37) noted that the band at 3,697 cm⁻ arose from a d po e oscillat on which was nearly perpend cular to the kao in'te sheets, the other three at 3,670, 3,652, and 3,620 cm^{-1} arose from a d pole osc l lat on nearly paralle w th the sheets.

Ledoux and Wh te (79) expanded kao in te with potassium acetate and hydraz ne fol owed by deuteration. They found the absorpt on frequency at 3,695 cm^{-1} shifted to lower va ues, but the intensity of the absorpt on band at 3,620 cm^{-1} was not affected by the treatment. The band at 3,695 cm^{-1} was correlated, they reasoned, with predom - nantly nner surface hydroxyls with the dipo e at r ght angles to the basa plane and the band at 3,620 cm^{-1} was related to inner hydroxy s with the dipole ncl ned toward the empty octahedral s tes. Weism er et al. (128) examined the differential nfrared spectra of f lms of montmorll on te w'th artifica ly introduced interlayers. They noted such inter ayers gave absorpt on bands at 3,695 and 3 570 cm^{-1} of nearly equal intensit es. The p echroism at 3,695 cm⁻ nd cated an orientation of many of the hydroxyls normal to the oxygen surface of the montmor onite. The non-plechroic nature at 3,570 cm^{-1} ndicated an orientat,on at a moderate ang e to the oxygen sur-

face for the balance of the inter ayer hydroxyls. A decrease in frequency from 3,570 to 3,600 cm⁻ upon dry ng was expla ned by dehydrat on and a closer association of the high frequency OH at 3,695 cm⁻ with the oxygen surface of the clay.

Lyon and Tuddenham (81), on exam nat on of the spectra due to Si-O and A -S -O between 1,124 and 999 cm⁻ , observed a d agnostic pair of doublets. The doublet at 935 and 909 cm^{-1} was typical of Al-O-OH bond ng of kaolin te and dick te, although only a single peak at 909 cm^{-1} appeared for hal oysite.

.nfrared spectras of soil clays

F e des et al. (41) invest gated sever so s derived from rhyo .t c and andesit'c volcanic ash, the infrared analys s was given for a sequence that .ncreased with both deposit ona age and solum depth, this was from al ophane B, allophane A, metahalloys te to kao in te Mejia et a (92) reported an infrared study of the weather- ing sequence of al ophane to halloys te In volcan c ash so s n the Colomb an Andes. Mitchell and Farmer (93), studying amorphous c ay m nerals in some Scottish so l profiles, found adsorbed water n clays that gave absorption bands near 3,333 and 1,667 cm^{-1} ar s ng from the stretch ng and bending vibrations, respectively They stated that the amount of sorbed water in the m neral component of the soil c ay has been taken as an ndication of the amorphous a umino-si icates present DeMumbrum (3), using nfrared analysis of soil clays from a Mississippi coastal terrace found a very strong hydroxyl absorpt on maximum at 3,597 cm^{-1} in the col o d contain ng large amounts of amorphous a umina He found the intensity of the absorpt on lessened as the substance was removed. DeMumbrum and Chesters (32) reported

that the infrared absorption spectra of a Tophan c soil concentrates from three Wiscons n podzol profiles showed the presence of unbonded hydroxy groups by absorption at 3,571 cm^{-1}, while the absorption maximum at 3,333 and 1,639 cm^{-1} are indicative of hydration. They noted that the presence of an amorphous siliceous component was indicated by the silicate-stretching area between 1, 1 and 909 cm^{-1} and some free opal was present from the slight absorption at 770 cm^{-1}. They concluded, upon comparison of the soil clay with amorphous standards, that these soil clays were similar to amorphous metal,c silicates and that the maximum at 1,429 cm^{-1} was attributable to ferr c silicates. Kunze and Bradley (75), from a study of tabular halloysite in a Texas soil, reported that the infrared pattern contained two major absorption bands at 3,690 and 3,620 cm^{-1}, attributable to hydroxy-stretching absorption. They interpreted the broad antisymmetrical stretching band in the region of 3,430 cm^{-1} as molecular water and an O-H flexion band at 915 cm^{-1} as the hydroxyls bound to two Al atoms. DeMumbrum and Jackson (33) found that copper and zinc saturation decreased the hydroxy absorption intensity at 3,571 cm^{-1} in montmorillonite, vermiculite, and kaolinite indicating reaction of these metals with octahedral hydroxyl groups. They noted the layer hydroxyl peak of kaolinite at 3,704 cm^{-1} was not affected. They reported the Cu treatment yielded an additional pair of peaks at 1,563 and 1,429 cm^{-1} whereas, Al and Fe treatment tended to increase peak intensity at 3,571 cm^{-1}. Klages (73), studying the A and C horizons from a forming sodic soil, reported that both horizons were characterized by a strong hydroxyl stretching vibration at 3,630 cm^{-1}. He attributed strong bands at 1,090, ,040, and 1,020

cm^{-1} to S -O stretching vibrations those at 9 8 and 880 cm^{-1} were assigned to R-OH bending.

Concentrat on of Elements in Soils and Plants

Gamb e et al. (50) reported that in the Panama-Co ombia study area the e emental concentrations are significantly different for geograph c and genetic groupings. However, no difference was found n data between extracts of soil from Panama and Co ombia except for Mn ndicating that the soils from both study areas were very s mi ar. The significantly higher Mn concentration in the Colombian soil extracts was attributed to the larger number of poor y dra ned Colombian so s. They also reported that mean e ementa concentrat ons between the principal food crops and between p ant compartments in these crops are different Few s gnif cant differences were reported for corn grain, rice gra n, and plantain/banana fru t grown in Panama and Colombia. L near corre ations analys s re at ng N, P, K, Ca, Sr, Mg, Fe, Mn, Cu, and Zn content of corn grain, rice grain, and plantain/banana fruit with those elements in the soi extract were also made Sign ficant regress ons were found only between the fo owing compar sons so l Ca and corn grain Ca, soil N and r ce grain N, soI P and rice grain P, and soil Mn and rice grain Mn.

M neral concentrations in soil extracts and re ated plant compositional analysis for agricultural crops and indigenous vegetation in Darien Province and comparable areas have been reviewed extensively by Gamble (48) and are well documented (8, 48, 54, 97, 20, 129)

Ion Distribution in Plant Roots

In plant roots, types of ion fractions have been suggested by Brouwer (24) to be ions in free space, exchangeable ions, and ions separated by membrane tissue.

Water Free Space

The bathing solution is first brought into contact with the cell walls of the root epidermis. These walls are metabolically inactive and are exterior to the location where work against a concentration gradient takes place. The cellulose acts similar to a wet sponge in that the solution moves continuously by simple diffusion. This volume and other filled voids that are in equilibrium with the bathing solution are referred to as water free space (26, 36, 56). This space is approximately 10% of the root volume (36, 56).

Exchangeable Ions in Roots

The primary constituents of the epidermal walls are cellulose fibers and pectin materials. The latter are acid, having carboxy groups which ionize to give H^+ and an anion held in the wall structure (56). Williams and Coleman (134) have stated that plant roots manifest a H^+ ion swarm associated with solid-liquid interfaces in a colloidal system and interact with neutral salts with the development of exchange acidity. This system can be considered as a double layer of cations associated with the root surface. This character of the pectin materials creates a Donnan system for salt distribution and for this reason Briggs and Robertson (23) called this volume Donnan free space of the root and this is in the order of 10 to 20% of the salt binding capacity of the root (56, 63, 77).

Donnan free space does not depend directly upon root metabol sm, since the same results are obta ned ndependent of temperature, w th either living- or ether-killed roots (56, 134) wil iams and Coleman (134) demonstrated that the entry of cat ons into the double ayer follows the type of lyotrop c series observed with many inorganic and organic exchange mater als The yotropic series in decreas ng order of replacing ab lity are H^+ Ba^{++} Ca^{++} Mg^{++} Cs^+ Rb^+ NH_4^+ K^+ Na^+ Li^+ Root tips and root hairs are the most act ve root portions with surface exchange properties (134).

In the measurement of cation-exchange capacity of roots, many workers have used H^+ as the saturating ion Smith and wallace (113) determ ned the cation-exchange capac ty of citrus, avocado, beans, and bar ey roots by immersing them from 60 sec up to 20 m n n dilute ac d Smith and wa lace (113) rep aced the ions by electrodia ysis, wh le Crooke (27) advocated the use of ac'd saturation of dried m l ed roots These techniques are val'd if the H^+ measured was only from the root cat on-exchange s tes Fiske l and Brams (42) reported that H^+ retention by the roots was the sum of H^+ in the free space and on the exchange sites. They also reported that the free space occupied by the acid after a ra ative y short nterval may approach or surpass the amount attributable to cation exchange

Exchangeable ions and uptake

Drake et al. (34) contended that the differences in the abi ity of plants to take up cations from the soil are largely control ed by the root-exchange capacity and the va ence of the cat on. They also stated that, under many field conditions, the cation content of the plant materia is arge y determ ned by physica -chemica relat ons

between the root and soil colloidal systems. These ideas were supported by Wiersum and Bakema (131) when they demonstrated the capability of roots to exert a regulative influence on the amount of mono- and di-valent cations absorbed. They demonstrated this adaptive variation for several species by employing the roots of a single plant, using split root-systems in amberlite + cation mixture and amberlite + anion mixture. It was shown, by this system, that root cation-exchange capacity is increased in a medium where the root must compete with the resin for cations, while the exchange capacity is somewhat lower in a medium where only anions are available. McLean et al. (87) noted that root exchange capacities were related to their nitrogen content. This phenomenon might partially be described by the fact that Hiatt (59), working with excised roots of barley, reported that organic acid content of the roots was related to differences in cation and anion absorption. He found that when the rate of increase of anion uptake exceeded the rate of increase of cation uptake there was a decrease in organic acid content of the roots.

Epstein (36) maintained that exchangeable surfaces or exchange spots on root surfaces are not identical with the entities involved in active transport. He noted that the amount of a given cation absorbed on these exchange spots can be minimized if an excess of another cation is present, preferably by one with more affinity for the exchange sites. He reported ion exchange reactions not to be a necessary step in cation absorption. This is supported by Lagerwerff and Peech (76) working with Rb and Ca. Fried et al. (47) also indicated that ions are adsorbed by specific ion-binding compounds

of the root. They reported that only negl gib e amounts of the cations tested were adsorbed non-spec fica ly However, even w th the most carefu measurements, they found a arge assortment of negative s tes on roots most of which are not specific in the adsorption of cations. Fr ed et al. (47) conc uded that cation-exchange va ues found for barley were ten-fold greater than the concentrat on of active adsorp tion s tes determined. O sen (98) supported the hypothesis that the driving force on an on s the e ectrochemical potential gradient extend ng at right angles through the periphery of the root and that the absorpt on process is actua ly a re,ative y simple d ffusion process wh'ch s not affected by adsorpt on mechanisms.

Barriers

Brouwer (24) stated that the tonoplast and p asmalemma are mpermeable to ons. Hendricks (56) favored the epiderma ce ls as the rate-limiting barriers to salt entry into the root. Slatyer (112) reported that the endodermis served as a barrier to solute transfer Bernstein and Haywood (11) suggested that the endodermis was the im t ng barrier to solute transfer from the interce ular spaces and can accumulate so utes not requ red for norma growth This s supported by Bowling and Spanswick (19) and Bowl ng et a (18) who treated the root simply as a membrane separating the sap from the external so ut on. They dentified th s membrane in part cular as a diffusion barrier at the endodermis.

Sequentia Extraction of Roots

The complexity of the cation uptake by roots and the mechan sm of th s uptake have made it diff cult to evaluate onic relationships

Frank n ,46) determ ned the amounts of Ca and K absorbed by excised barley, corn, and soybean roots after a l-hour immersion n 10^{-3} N chlor de so ut ons of Ca and K Cations were d sp aced by a series of successive rinses ranging in reaction from pH 2 to 12. He found a s gnif cant ,near correlation ex sted between the uptake of both Ca and K and the exchangeable ions wh ch were removed not by the first acid r nse but by subsequent r nses, mu tiple corre ation coeff cients ranged from 0.79 to 0.96.

The effect of the t me of immersion of roots in 1.0 N HCl on the remova of var ous ons was nvest gated by Fiske l and Brams (43) employing a sequence of 1.0 N HCl extractions. Exchangeable or easily replaceable cations were differentiated by a rap d wash with 1 0 N NH_4C prior to immersion times of 2, 7, 7, 37 97 277, and 1 000 minutes in 0 N HCl. They noted that the nternal cell-wall structure appeared to be unchanged from v sua and m croscop c inspection They a so found that .0 N NH_4C extracted appreciable K and Ca, whereas the f,rst mmers on n 1 0 N HC removed the greatest amount of Cu, La, and K in the acid sequence, Fe, Al, and P were incompletely extracted and were highest in many cases in the ash of the roots after the extraction sequence. The diagnost c use of these desorption analysis was suggested b, these authors for study of ions in the symp ast as a process of diffusion and for regression relationships between leaf and root ana ysis. F skel and Leonard (45) established linear regress on relationships between root and soil Cu, extractants employed were water, .0 N NH_4OAc at pH 4.8, and 1.0 N HC . They reported Cu content of the roots increased proportiona ly to the amount of Cu app ied n fertilizer. Foliar Cu-defic ency symptoms were noted where root Cu was less than 3 ppm of the fresh weight and Cu extracted with .0 N HCl was less than 2 ppm n the soil.

In work by Brams and F skel (22) so l analysis and corresponding root extraction ana ys s for Va encia oranges on rough lemon root stock were generally not found to be s gn ficantly correlated The lack of correlat on was attributed to the fact that five months lapsed after the last fert l zation and to a lack of appreciab e rainfa l two weeks pr or to sampl ng They further stated that under condit ons of more recent fertil zation and higher soil mo sture content, whether from ra nfal or rr gation, the so supply ng power to the roots wou d be expected to be more eff cient and thereby reduce the root-composition variability.

MATERIALS AND METHODS

Root, Leaf, and Soil Sampling and Analysis

Sample Locations and Collection

The experimental locations were in Darien Province of Panama located from 8°15' to 9°00' north latitude. The sampling was initiated in May, 1967, and terminated in September of that year. Leaves, feeder roots, and the soil adjacent to the roots of two agricultural crops were sampled. These were paragrass (Hyparrhenia rufa Nees) from fertilized field trials (51) and corn (Zea mays L.). In addition heliconia (Heliconia spp.) an indigenous, secondary-growth species, described by Smith (1114) and which is found in slash-burned areas immediately following agricultural production was sampled.

Samples were collected of the above species occurring at 2 locations (Appendix Table 53), in the Bioenvironmental Safety Feasibility Study area.

Sample Collection and Preparation

Root and soil sample collection and preparation

Healthy feeder roots were sampled from the surface soil to a depth of 12 cm at two or more sites at each location (Fig. 2). Root concentration was greatest at this depth from observation of pits dug at several sites. The soil immediately adjacent to the root was taken as the soil sample. The roots and adjacent soil were collected with a machete and approximately 1,500 g were placed in polyethylene bags

After returning to the field laboratory at Santa Fe the roots were separated manually from the soil, placed in a sieve and washed with tap water until free of soil particles. About 1,000 g of the damp, sieved soil were collected for each sample, stored in polyethylene bags, and labeled corresponding to the root sample. The soils shipped to the University of Florida were air-dried, ground to pass a 2-mm sieve, mixed, and stored until used.

Leaf collection and preparation

Leaf samples were collected from the same plants as the root samples. Corn leaves were sampled by collecting several leaves located at approximately two-thirds the height of each plant. Paraguagrass was sampled by randomly cutting areas of one square meter. Heliconia was sampled by taking leaves located about two-thirds the height of each plant and cutting sections six inches in length from the edge to the mid-rib of the leaf. Leaf samples were air-dried, stored in paper bags, and shipped to Panama City. Upon arrival there, the samples were oven-dried at 70C, ground to pass a 40-mesh screen, sealed in polyethylene bags, and labeled corresponding to the root samples.

Root extraction

Young, lateral roots approximately 3-cm long and 1- to 2-mm in diameter were excised from the previously washed root mass. The roots were then rinsed with deionized water, blotted dry on paper towels, weighed, and transferred to 95-ml polyethylene tubes.

The sequential desorption procedure developed by Fiskell and Brams (42) was used in two steps. In the first step, 50 ml of 1.0 N NH_4Cl were added to the roots and shaken for 30 seconds. The solution was drained into separate centrifuge tubes and designated as extract

( ). The roots were immediately rinsed with deionized water to remove excess NH_4Cl. In the second step, 50 ml of 1.0 N HCl were added and the roots intermittently shaken for 30 minutes. This solution was drained immediately into a centrifuge tube and designated as extract (II).

Each root extract was filtered through whatman No. 42 filter paper. Thirty ml of the filtrate from root extraction (I) were placed in a 50-ml volumetric flask. Four ml of concentrated HCl were added, made to volume with deionized water, shaken, placed in 70-ml polyethylene vials, and sealed. Thirty ml of root extract (II) were placed in a 50-ml volumetric flask, brought to volume with 1.0 N HCl, transferred to other vials, labeled, and capped. Root extracts I and II were stored in the approximately 1.0 N HCl to prevent bacterial growth.

The roots were then enclosed in leak-proof vials containing 5 ml of 1.0 N HCl for shipment to the laboratory at the University of Florida. Upon arrival the contents were transferred to quartz dishes, heated for one hour at 300C, and two hours at 575C. The ash was dissolved in 5 ml of hot 1.0 N HCl, filtered, washed with 5 ml 1.0 N HCl, and brought to a volume of 100 ml with distilled deionized water. These samples were designated as extracts (III). The combined root composition from extracts I, II, and III was designated as extract (IV). The root-ash residue was dried at 105C, weighed, and recorded as insoluble residue. The residue and filter paper were ashed, dissolved in 5 ml of perchloric acid, evaporated to dryness, and redissolved in 10 ml of 1.0 N HCl and made to 100 ml with distilled-deionized water and designated as extract (V). The remaining residue was dried at 105C, weighed, and recorded as perchlorate-insoluble residue.

Soil extraction

Fifteen grams of damp soil were transferred to a 90-ml polyethylene tube. Fifty ml of 1.0 N NH_4Cl were added and the soil was shaken intermittently for one hour. The suspension was filtered through Whatman No. 42 filter paper and the filtrate collected in 90-ml polyethylene centrifuge tubes. Thirty ml of the soil extract were transferred to a 50-ml volumetric flask, 4 ml of concentrated HCl added, and the solution made to volume with deionized water. The soil extracts were placed in 70-ml polyethylene vials, stoppered, labeled, and designated as soil extract (1). Soil was extracted with 1.0 N NH_4Cl instead of NH_4OAc at pH 4.8, which is an extracting solution more commonly used. The reasons for using 1.0 N NH_4Cl were the necessity and desirability of having an extracting solution, which could be acidified to prevent bacterial growth and one which did not drastically change the soil pH during extraction.

Wet-ashing of selected soils

An experiment was designed to measure the possible effects of contamination of soil adhering to roots, after washing steps on the composition of roots. The soils listed in Appendix Table 55 were moistened to a paste consistency on filter paper, dried, weighed, and ashed as described for the ashing of root samples. The ash was extracted with 1.0 N HCl and perchloric acid as mentioned above for insoluble root residue. The extract was designated as soil wet-ashing extract.

Leaf extraction

Two grams of leaf sample were transferred to Pyrex beakers and heated gradually to 550C. The material remained in the furnace until a grey ash was obtained. After ashing, the sample was allowed to cool,

an excess of concentrated reagent-grade HCl was added, and the excess acid evaporated by careful heat ng. The residue was then reheated to 550C in the furnace for 1-2 hours or until the residue was wh te If the residue was not white after extended heating, it was cooled and a few drops of 25% HNO_3 added. The residue was dried and reheated to 550C. After coo ing, 1 ml of concentrated HCl was added and the solut on made to a volume of 100 ml w th distilled-deion zed water

Soil Physical Analyses

So particle-size distribution

Particle-size distribution was measured after dispersing 25 g of a r-dr ed soil fe solutions of 5% sodium hexametaphosphate (Calgon). The particle-size separat ons were made us ng the hydrometer method as described by Day (29).

Soil-water retentiv ty

water retent vity was measured at 0 33 and 15 bars us ng the pressure-plate apparatus as described by Richards (109).

Soi Chemica Ana yses

Soi pH

The so I pH was determined by transferring 20 m of deionized water and 10 g of damp so to a 50-ml beaker. The mixture was stirred interm ttent y for one hour. The pH was then read us ng a standard g ass-e ectrode assembly and meter The meter was standard- zed with buffer so utions at pH 4 and 7 (101). The pH of the filtrate from the soil extract was determined as described above.

Soil organic matter

Organic matter was determined in dupl cate us ng 0.5 g of oven-dried soil and oxidized by chromic acid in H_2SO_4 with heat of dilution.

The Walkley-Black method for organic matter was used with the modification of Schollenberger described by Jackson (66) to compensate for the effect of higher Mn oxides

Titratable exchange acidity

Exchangeable acidity was determined on 10 g of air dry soil utilizing the barium chloride-triethanolamine method described by Peech (100) and calculated as meq per 100 g of soil.

Soil CEC

The cation-exchange capacity (CEC) was determined at pH 4.8 and 8.2. Five grams of air-dried soil were placed in 90-ml centrifuge tubes. The Na saturation of the exchange sites was achieved by washing three times with 50-ml aliquots of 1.0 N Na acetate (NaOAc) buffered either at pH 4.8 or 8.2 and followed by a 30-ml aliquot of 1.0 N NaCl solution. The soil samples were stirred thoroughly, centrifuged, and the supernatant discarded after each wash. The excess ions were removed by washing first with distilled deionized water and then 99% ethanol. The washing was continued until the conductivity of the supernatant was less than 4.0×10^{-3} milli mhos measured with a Barnstead 70 BC, conductivity bridge and a Yellow Springs 3403, conductivity cell with K = 1.0. The Na^{+} ions were effectively removed by suspending the clay in 30 ml of 1.0 N NH_4 acetate (NH_4OAc) at pH 7.0 using a rubber-tipped stirrer run at high speed to achieve thorough mixing. The clay was separated by centrifugation and the supernatant decanted into a 250-ml volumetric flask. The clay was washed twice more with 30 ml aliquots of 1.0 N NH_4 acetate. The supernatant was added to the previous extract and brought to volume with distilled-deionized water and shaken well. Seventy-five ml of this solution were transferred to plastic vials

for Na determination. This procedure was that described by Chapman (25) with modif cations n the wash ng mixtures, saturating techn ques, and conductivity measurement. The CEC s expressed in meq Na^+ per 100 g at pH 4.8 and 8.2

Soil extracts

Soil Ca.--Calcium was determined directly in the 1.0 N NH_4Cl so ut on for soil extract and the 1.0 N HCl solutions for the soil extracts from wet-ashed soils by atom c absorpt on (AA) spectroscopy. A Perkin-E mer 303, atomic absorption instrument was used emp oy ng an air-acetylene reducing f ame. Standards were made in the same reagents as the soil extracts. Analytica concentrates (J. T. Baker Chemical Co. Dilut- T) were used for the preparation of standards at 0, 2, 4, 6, 8, and 0 ppm Ca inc uding the addition of 0.5% of $LaCl_2$. The Ca-absorption values were read d rectly at a wavelength of 4,227A.

Soil Sr --Strontium was determined directly from soil extract s by atom c absorption spectroscopy. Standards were prepared, In the same reagent as the so extracts, at 0, 1, 2, 3, 4, 5 ppm of Sr. A reduc ng flame was used and the values read directly at a wavelength of 4,607A.

Soi Mg. -Maghes um was determ ned directly from so extract l and the wet-ashed so extracts by atomic absorption spectroscopy. Standards were prepared n the same solution m xtures as the soi extracts, at 0, 0.5, .5, 2 0, 2 5, and 3 0 ppm of Mg with the add t on of 0.5% $LaCl_2$ A reducing flame was used and the values read directly at a wavelength of 2,852A.

Soil Fe. -Iron was determined directly from soil extract l and the wet-ashed soil extracts by atomic absorption spectroscopy.

Standards were prepared, in the same solution mixtures as the soil extracts, at 0, 0.5, 1.5, 2.0, 2.5, and 3.0 ppm of Fe. An oxidizing flame was used and the values read directly at a wavelength of 2,483A.

Soil Mn.--Manganese was determined directly from soil extract I by atomic absorption spectroscopy. Standards were prepared, in 1.0 N NH_4Cl, at 0, 0.25, 0.50, 0.75, and 1.0 ppm of Mn. An oxidizing flame was used and the values read directly at a wavelength of 2,80 A.

Soil Zn.--Zinc was determined directly from soil extract by atomic absorption spectroscopy. Standards were prepared, in 1.0 N NH_4Cl, at 0, 0.5, 1.0, 1.5, and 2.0 ppm of Zn. An oxidizing flame was used and the values read directly at a wavelength of 2,138A.

Soil Cu.--Copper was determined directly from soil extract I by atomic absorption spectroscopy. Standards were prepared, in 1.0 N NH_4Cl, at 0, 0.25, 0.50, 0.75, and 1.00 ppm of Cu. An oxidizing flame was used and the values read directly at a wavelength of 3,247A.

Soil Fe, Mn, Zn, and Cu enrichment.--Soil extract I contained insufficient Fe, Mn, Zn, and Cu for normal detection in the soil extract solution. A 25-ml aliquot of soil extract was placed in an evaporating dish and taken to dryness with a few ml of concentrated HNO_3 added to permit decomposition of NH_4Cl. The remaining salts were taken up in 5 ml of 0.1 N HCl and analyzed by the same methods described in the above with the exception that standards were made in 0.1 N HCl.

Soil P.--Phosphorus was determined by the chlorostannous and reduced molybdophosphoric method in a sulfuric acid system as described by Jackson (66). Phosphorus was determined in soil extract (I) using 5-ml aliquots. The transmittance was measured at 660 mμ by a Beckman B spectrophotometer. Standards, using reagents corresponding to the

extract ng so ut on, were prepared at 0, . , .2, .3, .4 and .5 ppm of P. The standard curve obeyed Beer s law Phosphorus concentrat ons n the extract ng solut on were obtained from the standard curve and appropriate dilution factor.

Soi K.--Potass um was determ ned directly from aliquots of the so extract ( ) by flame em ssion spectrophotometry using the Beckman DU instrument employing an oxygen-hydrogen flame. The emiss on was read at 768 mμ. The K standards were prepared n 1 0 N NH_4Cl made to 1.0 N w th respect to HC , at 0, 4, 8, 12, 16, and 20 ppm. The concentrations of K n each were obtained from the p ot of percent emiss on and ppm of K and then corrected for sample d ution.

Soil CEC

Soi) Na.--Exchangeable Na was determined directly from aliquots of the extracts by flame photometry using a oxygen-acety ene flame. The Na emission was read at 589 mu. The Na standards were prepared, n 0.5 N NH_4OAc, at 0, 30, 50, 80, 100, 120, and 150 ppm. The concentration of Na in each was obta ned from the plot of percent em ssion and ppm of Na and then corrected for samp e d.lution.

Root Chemical Ana ys s

Root extracts

Root Ca, Sr, Mg, Fe, Mn, Zn, and Cu.--Root extracts I, II, and I were analyzed for Ca, Sr, Mg, Fe Mn, Cu, and Zn. These elements were determ ned d rect y n the extract ng so ut on by atom c absorption spectroscopy. Standards for extract I were made in a 2 5 mixture of 1.0 N NH_4Cl and 1.0 N HCl. Standards for extracts I and II were prepared in 1.0 N HC . The standard curves, type of f ame, and wavelength were the same as that described above for soil extracts. Calculations were made on fresh weight basis.

Root P.--Phosphorus was determined on extracts I, II, and III utilizing the Beckman B spectrophotometer. Standards for extract I were made in the mixed solution described above. Standards for extracts II and III were prepared in 1.0 N HCl. The standard curve and wavelength are the same as that described under soil P. Calculations were made on a fresh weight basis.

Root K.--Potassium was determined directly from aliquots of root extracts I, II, and III by flame photometry. Standards for extract I were made, in the mixed $\underline{N}$ NH_4Cl and $\underline{N}$ HCl solution, at 0, 5, 10, 15, and 20 ppm of K. Standards for extracts II and III were prepared in 1.0 N HCl at 0, 5, 10, 15, 20, 30, and 50 ppm. The flame and wavelength are the same as that described under soil extracts. Calculations were made on a fresh weight basis.

Leaf Analysis

Leaf extracts

Leaf Ca, Mg, and Zn.--The concentrations of Ca, Mg, and Zn were determined by Stewart Laboratories, Knoxville, Tennessee using a Beckman atomic absorption instrument. Description of the technique was reported by Gamble et al. (50).

Leaf Sr, Fe, Mn, and Cu.--Analyses for Sr, Fe, Mn, and Cu were also made by Stewart Laboratories by optical emission spectroscopy using a Bausch and Lomb quartz prism instrument. Description of the technique was reported by Gamble et al. (50).

Leaf K.--Potassium was determined directly from aliquots of the leaf extract by flame photometry. The standard curves, flame, and wavelength are the same as described for root extract I.

Properties of Soil Clays and Bentonite

Sample Selection

Eight of the soils from Panama (Fig. 3) were selected for detailed study of the clay fractions. These were considered to be representative of the major soil groups encountered in the field sampling, Appendix Table 45. Soil was taken at 0 to 12 cm in depth at these sites and brought to the laboratory as described previously. Location of these soils and some of their properties are reported in Table 1. As a reference, Wyoming bentonite (Ward's No. 25) was included in the study.

Sample Preparation

After dispersion with 0.5% hexametaphosphate, silt and clay fractions of the particle-size analyses were collected in 2-liter flasks. The fractions were concentrated by sedimentation, the excess liquid siphoned off, and the sediment transferred to 600 ml beakers. Free carbonates were removed by addition of 200 ml of 0.8 N NaOAc, buffered at pH 5.0 and allowed to stand for 2 hrs. The excess liquid was again siphoned off after sedimentation had taken place and organic matter oxidized with H_2O_2 as described by Kunze (74).

Following the removal of both soluble salts and organic matter, the sample was dispersed with 2% Na_2CO_3 and washed through a 200-mesh sieve. The less than 2μ fraction was separated by centrifuging as described by Whitting (130). Clay samples were placed in 90-ml polyethylene centrifuge tubes. This clay was designated as treatment (C_1) and the clay saved for further treatment.

Clay Extractions

Dithionite-citrate extraction

The clay samples from the above sample preparation were treated

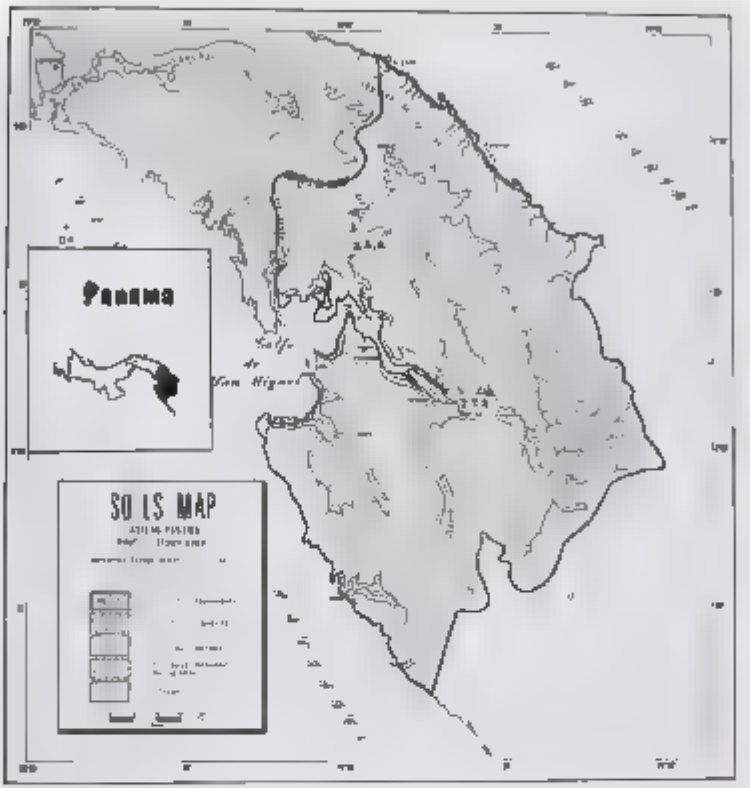

Fig. 3.--General soils map of Darien province located in eastern Panama. The inset numbers refer to locations of samples taken for clay characterization where is Patino, 2 is Yeviza, 3 is Santa Fe, 4 is Trocha, 5 is Rio Sabana, 6 is Rio Lara, 7 is Rio Chucunaque, and 8 is Rio Chico.

Source: Original map by Gamble and Ah Chu (50).

for the removal of free iron oxides. The method employed was essentially the same as that described by Kunze (74) and Mehra and Jackson (9). The clay was transferred to 90-ml polyethylene tubes. Forty ml of 0.3 M sodium citrate solution and 5 ml of 1.0 N sodium bicarbonate were added to the sample in the tube. These tubes were placed in a water-bath, heated to 80C, and 1.0 g of solid sodium dithionite added to each. After 5 minutes of intermittent stirring with a polyethylene-covered rod, the tubes were removed from the bath, and the clay precipitated by centrifuging. The clear supernatant was decanted into a 100-ml volumetric flask. The clay was resuspended in 30 ml of distilled-deionized water and stirred using a rubber-tipped stirrer run at high speed to achieve thorough mixing. The clay was separated by centrifugation. The supernatant was added to the previous extract and brought to volume with distilled-deionized water and shaken well. Seventy-five ml of this solution were transferred to a plastic vial and designated as clay extract (1). The clay remaining was designated as treatment (C_2).

Sodium hydroxide extraction

The clay remaining after the above dithionite-citrate treatment was heated to nearly 100C in a boiling water-bath. Fifty ml of boiling 0.5 N sodium hydroxide were added to the clay and stirred intermittently for a period of five minutes which is a slightly modified procedure for the removal of amorphous aluminosilicates, hydrous silica and alumina described by Jackson (68) and has been used by Kashirad et al. (70). The tubes were removed and the reaction quenched by placing the tubes in a cold-water bath. The clay was separated by centrifugation and the supernatant decanted into a 100-ml volumetric flask. The clay was resuspended in 30 ml of distilled deionized water

using a rubber-tipped stirrer run at high speed. The clay was separated again by centrifuging, the supernatant added to the previous extract, brought to volume with distilled-deionized water, and shaken well. Seventy-five ml of this solution were transferred to a plastic vial and designated as clay extract (II).

Sodium dithionite-citrate, as described above, was added to the clay. The clay was separated by centrifugation and the supernatant decanted into a 100-ml volumetric flask. The clay was resuspended in 30 ml of distilled-deionized water using a rubber-tipped stirrer run at high speed. The clay was separated by centrifugation. The supernatant was added to the previous extract, brought to volume with distilled-deionized water, and shaken well. Seventy-five ml of this solution were transferred to a plastic vial and designated as clay extract (II). The clay remaining was designated as treatment (C_3).

Acid ammonium fluoride extraction

The clay remaining after the above sodium hydroxide and dithionite-citrate extractions were treated with a procedure designed for removal of interlayer materials. The reagent was 0.1 N HCl + 0.4 N NH_4F + 1.0 N NH_4Cl as described by Rich and Singh (108). The procedure was modified by allowing 40 ml of the reagent to remain in contact with the clay and intermittently stirred for 10 minutes. The clay was precipitated by centrifuging and the clear supernatant decanted into a 100-ml volumetric flask. The clay was resuspended in 30 ml of 1.0 N NH_4Cl and stirred using a rubber-tipped stirrer run at high speed to achieve mixing. The clay was separated by centrifugation and the supernatant added to the previous extract. This was brought to volume with distilled-deionized water and shaken well. Seventy-five ml of this solution were transferred to a plastic vial and designated

as clay extract (IV) The clay remaining was designated as treatment (C_4). The four sequential clay-extraction steps were repeated several times because of the large quantities needed for various analyses.

Clay Physical Analyses

Weighing

Duplicate samples consisting of 25 ml aliquots of the original clay suspension were placed in 90-ml centrifuge tubes. The clays were given the same sequential extraction treatments described previously. Samples were transferred to weighed plastic vials and the vials placed in an oven at a temperature of 40C for one week. The vials were taken from the oven, placed in a desiccator containing silica gel and weighed after cooling to room temperature. The weights were determined for treatments C_1, C_2, C_3, and C_4.

Thermogravimetric analysis

Duplicate samples of treatments C_1 and C_4 were transferred to weighed beakers. The samples in the beakers were placed in an oven at a temperature of 105C for 48 hours. The beakers were taken from the oven, placed in a desiccator containing silica gel, and weighed after cooling to room temperature. These same samples were placed again in the oven at a temperature of 200C for 48 hours. The beakers were then taken from the oven, placed in the desiccator, and weighed after cooling to room temperature. The percent loss in weight was calculated.

Differential thermal analysis

Clay treatments C_1, C_2, C_3, and C_4 were dried at 40C for a period of one week. A 35-mg portion of this clay was mixed with

67 mg of asbestos which had been fired at 1,000C and passed through a hammer-mill fitted with a fine screen. This mixture was then ground in an agate mortar until visually homogenous. The mixture was transferred to one of the four sample positions in the insert holder for the DTA apparatus and gently tamped into place using the packing tool. In the paired reference holder, the fired asbestos was tamped similarly. All four clay treatments were run simultaneously with clay treatments C_1, C_2, C_3, and C_4 placed in sample holders 1, 2, 3, and 4, respectively. Standard clay minerals used were Ward's kaolinite No. 4, ward's halloysite No. 2, and ward's bentonite No. 25. The standard clays were run in a similar manner as that above for the soil clays. Four pairs of DTA comparisons were used in this Deltatherm nickel assembly. Each pair was connected to a transistorized circuit, run at 25% sensitivity, using a heating rate of 10C per minute from room temperature, usually 23C, to 900C. Endothermic reactions from 50 to 200C and 200 to 900C were measured by tracing the endothermic peak patterns on glazed weighing paper of uniform texture and weight, cutting out the endothermic trace, and weighing. Use of the slope ratio of the endothermic peak sides as an index of kaolinite and halloysite were made as described by Bramao et al. (21) and Dean (30). The tangents to the angles made with the sides of the peak and the perpendicular are represented by the terms 'a' and 'b'.

X-ray-diffraction patterns

A portion of clay treatment C_1, C_2, C_3, and C_4 were prepared for X-ray-diffraction patterns as recommended by Whittig (130). Aliquots of clay treatments C_1, C_2, C_3, and C_4 were transferred to 90-ml centrifuge tubes and Mg saturated. Magnesium saturation was initiated

by adjusting the pH of the suspension to between 3.5 and 4.0 by adding 0.1 N HCl drop-wise with stirring. Ten ml of 10 N $Mg(OAc)_2$ were added to the suspension. The suspension was stirred rapidly with a rubber-tipped stirrer and the clay precipitated by centrifugation. The clear supernatant was discarded and the exchange-saturation step completed by washing the sample two times with 20-ml aliquots of 1.0 N $Mg(OAc)_2$ and two times with 20-ml aliquots of 1.0 N $MgCl_2$. After exchange saturation was complete, the excess salt was removed from the sample by washing with mixtures of distilled-deionized water and ethanol. Washing was continued until the conductivity of the supernatant was less than 4.0×10^{-3} milli mhos. Approximately 2 ml of distilled-deionized water and 2 drops of glycerol were added to the Mg-saturated clay. The sample was thoroughly mixed to facilitate glycerol solvation.

Potassium saturation was achieved by first transferring an aliquot of the clay suspension to 40-ml centrifuge tubes. The clay was then flocculated by the addition of 30 ml of 1.0 N KCl and stirred rapidly with a rubber-tipped stirrer. The suspension was centrifuged and the supernatant solution discarded. The exchange saturation was completed by washing the sample four times with 20-ml aliquots of 1.0 N KCl. After exchange saturation was completed the excess salt was removed from the sample by washing with mixtures of distilled-deionized water and ethanol. Washing was continued until the conductivity of the supernatant was less than 4.0×10^{-3} milli mhos. Approximately 2 ml of distilled-deionized water were added to the K-saturated clay and stirred thoroughly.

Oriented aggregate specimens were formed directly from the Mg-saturated, glycerol-solvated and K-saturated clays by pipetting some

of each suspension on a glass m croscope-cover slip. The suspens on was a lowed to dry at room temperature without disturbance to obtain max mum orientation of the clay particles.

The prepared sl des were processed for the X-ray-diffract on patterns using a Phill ps Norelco diffractometer with Cu Kα radiat or and a Geiger tube detector. Operating cond t ons for this instrument were a current of 16 ma at a sett ng of 40 Kv w th ,500 V on the Geiger tube. The sensitivity was x2x50 counts per second The scanning speed was 1^{o} per minute and a chart speed of 2.5 cm per minute The angles were converted to angstrom units (A) from charts prepared by Virginia Po ytechnic nstitute (126) and by X-ray-diffrac tion patterns of Ward s kaolinite No. 4 and Ward s bentonite No. 25. The X-ray instrument was calibrated using the 3.35 A ine of quartz as the standard.

Infrared spectrometry analysis

The absorpt on in the nfrared region of the clay m nerals was examined with a Perkin-Elmer 700 IR, spectrophotometer. Sodium-saturated clays were dr ed at 40C and pulver zed n a mortar. A mixture cons sting of 0.5 mg of the ground Na-saturated c ay and 50 mg of spectroscopic-grade KBr was used to form a transparent pel et. Th s pel et was formed using a KBr m ni-press as described by Perkin-Elmer (102). Pel ets were prepared and scanned (from 4,000 to 650 cm^{-}) for clay treatments C_1, C_2, C_3, and C_4. Ward s kao in te No. 4 and ward's halloysite No. 12 were scanned to faci itate interpretations. The percent transmittance was adjusted to 80% at 2,000 cm^{-} for each pellet before scann ng. The scan speed was eight m nutes from 4,000 to 650 cm^{-1}. The instrument was ca ibrated by scanning a standard polystyrene film from 4,000 to 650 cm^{-1}.

Specific surface

Portions of clay treatment C_1, C_2, C_3, and C_4 were transferred to 90-ml polyethylene centrifuge tubes and Ca saturated. Calcium saturation was achieved by adding 30 ml of 1.0 N $CaCl_2$ and stirring rapidly with a rubber-tipped stirrer. The suspension was centrifuged and the supernatant liquid discarded. The exchange saturation was completed by washing the sample two more times with 1.0 N $CaCl_2$. After exchange saturation was completed, the excess salt was removed from the sample by washing with mixtures of distilled-deionized water and ethanol. Washing was continued until the conductivity was less than 4.0×10^{-3} mhos. The clay was resuspended with approximately 5 ml of distilled-deionized water and transferred to weighed plastic vials. The vials were placed in an oven and dried at 40C for two days. Specific surface was determined as recommended by Mortland and Kemper (96). The samples were removed from the oven and placed in a vacuum desiccator containing 250 g of P_2O_5. The desiccator was evacuated by applying a Cenco Hyvac, vacuum pump for one hour. The stopcock was closed and the sample left in the desiccator for 2 hours or until a constant weight was obtained. The sample was wetted with glycol by distributing the liquid drop-wise from a pipette and warming for a few minutes in an oven at 40C. The samples were placed in a desiccator over 200 g of $CaCl_2 \cdot$ glycol solvate and the desiccator evacuated by applying the vacuum pump for one hour. After 24 hours the vacuum pump was used again for 30 minutes to remove foreign vapors. After 48 hours the vacuum was released and the samples weighed. The samples were returned to the desiccator after weighing and the vacuum applied for 30 minutes. This operation was repeated at 12-hour intervals until a constant weight was obtained.

Clay Chemical Analyses

Clay CEC

The CEC of the clay was determined at pH 4.8 and 8.2 for treatments C_1, C_2, C_3, and C_4. An aliquot of the clay suspension was placed in 90-ml centrifuge tubes and the cation-saturation procedure described under soil CEC was employed.

Clay extraction

Clay Fe.--Iron was determined directly from clay extracts I, II, III, and IV by atomic absorption spectroscopy. Standards were prepared at 0, 4, 8, 12, 16, and 20 ppm of Fe in 0.12 N Na citrate + 0.05 N Na_2HCO_3 + 1.0 g of solid $Na_2S_2O_4$ for clay extracts I and III, 0.25 N NaOH for clay extract II, and 0.2 N NH_4F + 0.5 N NH_4Cl + 0.05 N HCl for extract IV. An acetylene-air oxidizing flame was used and the values read directly at 2,483A.

Clay Al.--Aluminum was determined directly from clay extracts I, II, III, and IV by atomic absorption spectroscopy. Standards were prepared in the same solution mixtures, as the clay extracts for Fe determination, at 0, 30, 50, 80, 100, 150 ppm of Al. A nitrous oxide-acetylene flame was used and the values read directly at a wavelength of 3,093A.

Clay Si.--Silicon was determined directly from clay extracts I, II, III, and IV by atomic absorption spectroscopy. Standards were prepared in the same solution mixtures, as the clay extracts for Fe, at 0, 30, 50, 80, 100, and 150 ppm of Si. A nitrous oxide-acetylene flame was used and the value read directly at a wavelength of 2,516A.

Clay CEC

Clay Na.--Exchangeable Na was determined directly from aliquots

of the NH_4OAc extracts by flame photometry. The same instrument settings were used and the standards prepared in an identical manner at the same concentrations as described under soil Na.

Clay Cl.--Chloride was determined directly from aliquots of the NH_4OAc extracts by a specific ion electrode for Cl. A pH meter (Sargent, Model DR) and chloride electrode (Beckman Orion, Model 94-17) coupled with a calomel reference electrode were used. Standards were made in 0.5 N NH_4OAc at 0, 10^{-5}, 10^{-4}, 10^{-3}, 10^{-2} and 10^{-1} M of Cl. Chloride concentration was determined by plotting chloride against emf on 5-cycle log paper.

Clay F.--Fluoride was determined directly from aliquots of the NH_4OAc by a specific ion electrode for F. Standards were made in 0.5 N NH_4OAc at 0, 0.1, 1, 10, 100, and 1,000 ppm of F. Fluoride concentration was determined by plotting F^- against emf on 5 cycle log paper.

Correction Factors

Estimation of Root Contamination

The molar concentrations of Fe, Ca, and Mg that were insoluble in 1.0 N HCl but soluble in perchloric acid were determined. An estimation of soil contamination was made (Appendix Table 55) by determining the molar concentrations of Fe, Ca, and Mg in root extract V and the soil wet-ashing extraction of the perchlorate residue. The following equation was employed for this estimation.

$$\text{Estimated contamination} = \frac{R}{S} \times 100 \qquad [1]$$

where R is the sum of Mg, Ca and Fe in root extract V expressed in moles $X10^{-4}$ per 100 g and S is the sum of mean Mg, Ca and Fe in the soil wet-ashing extraction expressed in moles $X10^{-4}$ per 100 g.

A correction factor was not applied to the data because the (Mg + Ca) Fe molar ratios for root extraction V was 0.10 compared to 0.76 for soil wet-ashing extraction and the average estimated contamination was only 7.65%. The large difference in the (Mg + Ca) Fe molar ratios indicated that substantial amounts of the Fe measured in root extraction V are probably Fe precipitated either on the root surface or in the root and not from soil contamination. This would result in an exaggeration in calculated contamination.

Estimation of the Effect of F on CEC

The effect of F on the Na-exchange capacity after treatment with acid NH_4F was estimated. Eight samples of Ward's bentonite No. 25 were placed in 30-ml centrifuge tubes and given the sequential extraction described previously. The samples were Na saturated sequentially at either pH 4.8 or 8.2 as described in Appendix Table 47 and the cation-exchange capacity determined. An estimation of the effect of F was made using the following equation.

$$\text{Correction factor} = \frac{A - B}{A} \qquad [2]$$

where A is the concentration of Na, expressed in meq per 100 g, for samples X_1 to X_8 which contained large concentrations of F. The term B is the concentration of Na, expressed in meq per 100 g, for samples X_1 to X_8 upon resaturation where little or no F was present.

Statistical Analyses

Field Samples

The data were processed by punching the desired information on computer cards and obtaining a reduction of the raw data. The raw data were reduced by obtaining a simple data description printout on each sample group (124). Either a multiple range comparison of means to accommodate unequal replication or a 't' test for unpaired observations and unequal variances as described by Steel and Torrie (117) was made on specific groups of interest.

For each of three species Hyparrhenia rufa, Zea mays, and Helicoria spp., regression equations relating the element content of the plant with the element content of the soil were estimated. The elements considered were K, Ca, Sr, Mg, Fe, Mn, Cu, and Zn. Also the relationship between the soil and the root and leaf analyses using the corresponding mole-fraction (71, 132) and -ratio (70, 112) values for two elements were considered. These equations were as follows:

$$\text{Mole fraction } X_1 = \frac{K}{K + \sqrt{Ca + Mg + Sr}} \quad [3]$$

$$\text{Mole fraction } X_2 = \frac{\sqrt{Sr}}{K + \sqrt{Ca + Mg + Sr}} \quad [4]$$

$$\text{Ratio } R_1 = \frac{K}{\sqrt{Ca + Mg + Sr}} \quad [5]$$

$$\text{Ratio } R_2 = \frac{\sqrt{Sr}}{K + \sqrt{Ca + Mg}} \quad [6]$$

where the concentrations of elements are expressed in moles per liter.

In each case the hypothetical relationship was of the form

$$Y = b_0 + b_1 X + b_{11} X^2 \qquad [7]$$

where Y is the element content of the soil, X is the element content of the plant, and b_0, b_1, and b_{11} are constants. For each element, five different bases for the independent variables were considered. These represent the four different root values which were after the NH_4Cl, HCl, ashing and the total of these. The fifth was the leaf content.

Each regression equation was determined in such a manner that the quadratic term was included only if it made a significant reduction in the residual mean square after fitting the linear term. To determine significance a confidence level of 95% was employed.

Effect of Clay Treatments

Designs

The experimental designs employed were (1) a randomized complete block design consisting of a 9x4x2 with three replications to evaluate the contribution of amorphous and crystalline clay fractions of the pH-dependent and total cation-exchange capacity and (2) a completely randomized design consisting of a 9x4 factoral with two replications to evaluate the effect of amorphous and crystalline clay fractions on the specific surface.

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[1]Personal communication with Dr. Frank G. Martin, Department of Statistics, University of Florida, Gainesville.

Analysis

The significance of the cation-exchange capacity and the specific surface analysis was evaluated by analysis of variance. The sequential clay extractions were analyzed orthogonally. Significant interaction in the analysis of variance was examined for certain simple effects at the expense of a loss of replication (117). Comparisons of means were made using Duncan's new multiple range test (117)

RESULTS AND DISCUSSION

Properties of Soil Clays

Characteristics of Soils from which Clays Were Separated

Soil characteristics

The physical and chemical properties of soils, from which the clay fraction was separated, are listed in Table 1. Generally, the soils are slightly acid ranging from pH 5.6 for soil 4 to pH 6.6 for soils 1, 3, 5, 6, and 8. The organic matter content was high ranging from 4.6% for soil 5 to 13.2% for soil 6. The amount of clay present in these soils is large ranging from 20% for soil 8, which was a sandy loam, to 64% for soil 4 which was of clay texture. The water retention and CEC correspond closely to the amounts of organic matter and clay present in these soils. Similarly the titratable exchange acidity corresponds to the observed difference in CEC between pH 4.8 and 8.2. Profile descriptions for these soils are given in Appendix Table 45.

Effect of Treatments on CEC of Clays

CEC of clays before dissolution treatments

CEC at pH 4.8.-- Data summarized in Table 2 show significant differences between clays for CEC at pH 4.8. Soil clay 8 (Table 3) had a significantly higher CEC of 65.7 meq per 100 g than all other clays measured with the exception of clays 2, 3, 5, and Wyoming

Table --Characteristics of some surface soils from eastern Panama

Location		pH	Organic matter	Clay	Texture	Water retention		CEC		Terra alba exchange acidity
Name	No	H_2O				bar 1/3	bar 15	pH 4.2	pH 8.2	
			%	%		%		meq. 00 gm soil		
Patino	1	6.6	8.2	46	Clay	39.9	27.6	6.5	22	4
Yaviza	2	5.9	7.3	42	Silty clay	54.8	25.6	7.0	5.3	9.7
Santa Fe	3	6.8	7.2	44	Clay	5.9	27.4	6.5	3	2
Trocha*	4	5.6	4.7	64	Clay	55.2	28	5	28.2	2.4
Rio Sabana	5	6.6	4.6	44	Clay	48.5	27	17.3	37.4	8.5
Rio Lara	6	6.6	13.2	48	Clay	7.4	27.5	21.2	32.0	6.1
Rio Chucunaque	7	6.1	7.0	40	Silty clay	51.3	25.5	9	30.2	10.0
Rio Chico	8	6.6	6.0	20	Sandy clay loam	24.7	4.9	6.8	20.6	4

*A poorer (non-agricultural) area where proposed route 17 traverses the Isthmus

Table 2.—Analysis of variance of CEC for nine clays, at two pH values, after two sequential dissolution treatments

Source	Df	Sum of squares	Mean square	F' value
Block	2	145.2	72.6	2.41
Clay (A)	8	64,579.6	8,072.4	268.99**
pH (B)	1	6,924.0	6,924.0	230.72**
Sequential dissolution (C)+	(2)	3,020 5	1,510 3	50.30**
C_1 vs C_2		694.6	694 6	23 4**
(C_1+C_2) vs C_3		2,325.9	2,325.9	77.50**
B X C_1 vs C_2		254.8	254 8	8.50**
B X (C_1+C_2) vs C_3		95 5	95.5	3. 8
A X B	8	,583 7	197.9	6.60**
A X C	16	3,898 0	243.6	8.12**
A X B X C	16	468.3	29.3	0 98
Error	100	3,001.5	30 0	

**Significant at P = 0.01.

+Symbol C_1 refers to clay before dissolution steps, C_2 after dithonite citrate treatment, C_3, after 0.5 N NaOH and associated dithonite treatment.

Table 3.--Mean values of CEC for the nine original clays before sequential dissolution treatment

	Before treatment		
	CEC		
	pH		pH dependent
Clay	4.8	8.2	
	meq/100 g		
I	29.2 c*	38.3 d	9.1 bc
II	57.7 ab	66.0 bc	2.3 c
III	60.5 ab	67.0 bc	6.5 c
IV	8.9 d	22.4 e	3.5 c
V	62.5 ab	73.0 b	10.5 bc
VI	48.4 b	50.8 c	10.4 bc
VII	55.4 b	62.4 c	7.0 c
VIII	65.7 a	83.2 a	17.5 b
Wy. bent.	59.5 ab	86.5 a	27.0 a

*Entries in each column followed by the same letter are not significantly different at P = 0.05.

benton te. The CEC of these clays were 57.7, 60.5, and 59.5 meq per 100 g, respectively. Clays 6 and 7 had exchange capacit es of 48.4 and 55.4 meq per 100 g which were signif cantly arger than the exchange capac ties of soil c ays 1 and 4, but were not s gn f cantly d fferent from those of so l clays 2, 3, 5, and Wyoming bentonite. C ay had a signif cant y h gher CEC at 29.2 meq per 00 g than clay 4 w th an exchange capacity of 8.9 meq per 100 g wh ch was the owest va ue measured.

CEC at pH 8.2.--The CEC signif cant y increased (Tab e 2) upon sa.urat on w th Na at pH 8.2. Soil clay 8 (Tab e 3) and Wyoming benton te had signif cantly h gher CEC at 86.5 and 83.2 meq per 00 g, respectively, than all other soil clays. C ay 5 had a s gn f cantly h gher CEC which was 73 0 meq per 00 g, than soil clays , 4 6, and 7, but was not sign f cant y different from clays 2 and 3 w th CEC of 66.0 and 67.0 meq per 100 g, respective y. The CEC va ues for c ays 6 and 7 of 58.8 and 62.4 meq per 100 g, respectively, were signif-cantly higher than the exchange capac ties for clays and 4, but were not s gn f cantly different from those of clays 2 and 3 Clay 1 had a CEC of 38.3 meq per 100 g which was s gnif cantly higher than clay 4 with an exchange capacity of 22.4 meq per 100 g.

pH dependent CEC.--Data summar zed n Table 2 show that s gn f-cant differences exist between c ays for the pH-dependent CEC. The pH-dependent CEC of Wyoming benton te (Table 3) was 27.0 meq per 100 g which was signif cantly h gher than all other c ays. Soil clay 8 had a pH-dependent CEC of 7 5 meq per 00 g wh ch was signif cant y higher than those for soi clays 2, 3, 4, and 7, but was not sign f cantly larger than those of soil clays 1, 5, and 6 wh ch had pH-dependent CEC

of 9.1, 0 5, and 10.4 meq per 100 g, respective y. Soil clays 2, 3, 4, and 7 with pH-dependent CEC of 2.3, 6.5, 3.5 and 7.0 meq per 100 g, respect vely, were not signif cant y different from so clays 1, 5, and 6.

Effect of Na dithion.te-c.trate

Averaged CEC.--From the analysis of variance (Table 2) there was a signlficant Interaction between clays and effects of the Na dith o-n te-c trate dissolution step on CEC Examination of th,s nteraction (Table 4) showed that dithion te-citrate s gnificantly ncreased the CEC when compared to the orlginal c ay averaged over both pH values, because of the ncreased exchange capacity of clays 2, 5, 7, and 8, and a decrease in CEC for clay 6 The increases ranged from 6.3 to 21. meq per 100 g and the single decrease was 7.6 meq. The other clays remained uncharged by the treatment. Further examination of the interact on (Table 4) showed that the CEC of c ay 8 was the largest single contributing factor to this significant interaction.

pH-dependent CEC.--From the analys s of variance (Table 2) there was a significant interaction between effects of the Na dithionite-c trate dissolut on and clays. When averaged over all nine clays, there was a sign ficant increase of 3.07 meq per 100 g in pH-dependent CEC. When this nteract on is examined by a multiple-range compar son of the means (Tab e 5), the d thionite-citrate treatment compared to the or ginal clays s gnif cant y ncreased the pH-dependent CEC of soil clays 2, 3, 7, and 8. The increase expressed in meq per 100 g was from 8 3 to 19.7 for c ay 2, from 6.4 to 19.7 for clay 3, from 7.0 to 25.7 for clay 7, and from 17.5 to 29.8 for clay 8.

Table 4. Mean values for CEC of clays before and after treatment with Na dithionite-citrate

Clay	Treatment: Original (C_1)	Treatment: After dithionite-citrate (C_2)	'F' Values
	------Mean CEC, meq/100 g------		
1	33.7	36.5	0 78
2	61.9	70.	6 69*
3	63.8	68.2	94
4	20.7	23.2	0 63
5	67.7	74.0	3.95*
6	53.6	45.8	6.13*
7	58.9	66.9	6.32*
8	74.5	95.6	44.58**
Wy. bent.	73.0	73.2	.01

*Significant at P = 0.05.

**Significant at P = 0.01.

Table 5 --Mean values for pH-dependent CEC before and after treatment with Na dithionite-citrate

Clay	Treatment	
	Original	After dithionite-citrate
	meq/100 g	
	9. a*	10.8 a
2	8.3 b	19.3 a
3	6.4 b	19.7 a
4	3.5 a	7.0 b
5	10.6 a	9.6 a
6	0.4 a	6.6 a
7	7.0 b	25 7 a
8	17.5 b	29.8 a
wy. bent.	27.0 a	26.5 a

*Entries followed by the same letter in each row are not significantly different at P = 0.05.

Effect of 0.5 N NaOH

Averaged CEC.--From the analysis of variance (Table 2) there was a significant interaction between clays and effect of treatment with 0.5 N NaOH. Examination of this interaction (Table 6) showed that the significant increase in CEC of the 0.5 N NaOH treatment compared to the first two treatments was because of the increased CEC in soil clays 2, 3, 5, and Wyoming bentonite. These clays increased in CEC, as meq per 100 g, from 66.0 to 74.9 for clay 2, from 66.0 to 89.9 for clay 3, from 70.9 to 79.5 for clay 5, and from 73. to 93.0 for Wyoming bentonite. The CEC of the other clays remained unchanged. Further examination showed that Wyoming bentonite contributed to most of this interaction. The increases in CEC of the Wyoming bentonite was attributed to the removal of hydroxy-Al interlayers.

pH dependent CEC --From the analysis of variance for pH-dependent CEC (Table 2) there was not a significant interaction between clays and the effect of NaOH dissolution, when averaged over all clays. When the interaction within clays was examined (Table 7) the pH-dependent CEC of soil clay 7 and 8 significantly decreased. These decreases, expressed in meq per 100 g, were from 16.4 to 8.7 for clay 7 and from 23.7 to 14.0 for clay 8. The pH-dependent CEC of all other clays was not significantly changed by the NaOH.

Effect of acid NH_4F

No accurate CEC values could be determined after treatment of clay with acid NH_4F because of a complex reaction between Na, F, and Al which resulted in formation of a slightly soluble Na aluminofluoride of variable composition and not simply Na cryolite ($3NaF.AlF_3$). Data for CEC and concentrations of F and Al found in these extracts are presented in the Appendix Table 47.

Table 6.--Mean values for CEC before and after treatment with 0.5 N NaOH

Clay	Treatment: Original + dithionite-citrate ($C_1 + C_2$)	Treatment: After 0.5 N NaOH (C_3)	'F' value
	meq/100 g		
1	35.1	34.2	0.13
2	66.0	74.9	10.46**
3	66.0	89.9	76.14**
4	21.9	26.4	2.69
5	70.9	79.5	9.76*
6	49.7	54.9	3.54
7	62.9	60.5	0.77
8	85.0	89.9	3.12
Wy. bent.	73.1	93.0	52.92**

*Significant at P = 0.05.

**Significant at P = 0.01.

Table 7.--Mean values for pH-dependent CEC before and after treatment with 0.5 N NaOH

Clay	Treatment: Original + dithionite-citrate ($C_1 + C_2$)	Treatment: After 0.5 N NaOH (C_3)
	------Mean, meq/ 00 g-------	
1	10.0 a*	9.0 a
2	13.8 a	12.6 a
3	13.1 a	12.4 a
4	5.3 a	4.2 a
5	10.1 a	4.2 a
6	8.5 a	7.9 a
7	16.4 a	8.7 b
8	23.7 a	14.0 b
Wy. bent.	26.8 a	24.9 a

*Entries followed by the same letter in a row are not different at P = 0.05.

Effect of sequential dissolution on CEC

pH dependent CEC.--The analysis of variance (Table 2) showed a significant interaction between pH-dependent CEC of the clays and the sequential treatments. Examination of this interaction (Table 8) showed that the CEC determined at pH 8.2 was significantly higher for each clay when averaged over all treatments with the exception of clay 4. This indicated that all clays with the exception of clay 4 are composed of minerals that exhibit an increase in CEC with an increase in pH.

Effect of Treatments on Specific Surface of Clays

Specific surface of clays initially

Data summarized in Table 9 show significant differences between clays for specific surface. Wyoming bentonite (Table 1) had a significantly higher specific surface of 697 M^2 per g than all other clays measured. Clay 5 had a specific surface of 473 M^2 per g which was significantly larger than clays 1, 2, and 8, but was not significantly different from clays 3, 4, 6, and 7. The specific surface of these clays was 361, 414, 377, and 364 M^2 per g, respectively. Clay 3 had a significantly higher specific surface 341 M^2 per g than all other clays, but was not significantly different from clays 3, 4, 6, 7, and 8. Clay 1 with 213 M^2 per g had a lower specific surface than all other clays, with the exception of clay 8 which had a specific surface of 268 M^2 per g.

Effect of Na dithionite-citrate

From the analysis of variance (Table 9) there was a significant interaction between clays for the effect of Na dithionite-citrate on specific surface measurements. Examination of this interaction

Table 8.--Mean values for pH-dependent CEC over a l treatments

Clay	Mean CEC			'F' value
	pH 8.2 (b_1)	pH 4.8 (b_2)	$b_1 - b_2$	
	meq/100 g			
1	39.6	30.0	9.6	13.88**
2	75.7	62.2	13.5	27.10**
3	80.3	67.5	12.8	24.78**
4	25.9	21.0	4.9	3.6
5	77.8	69.7	8.1	9.92**
6	55.6	47.3	8.3	10.33**
7	69.0	55.2	13.8	28.52**
8	96.8	76.4	20.4	62.49**
wy. bent.	92.8	66.7	26.1	102.27**

** Sign ficant at P = 0.01.

Table 9.--Analysis of variance of specific surface for nine clays after three sequential dissolution treatments

Source	Df	Sum of squares	Mean square	'F' values
Clays (A)	8	845,540.0	106,817.5	75.58**
Sequential dissolutions (C)	(3)	276,608.0	92,202.7	65.24**
C_1 vs C_2	1	24,544.5	24,544.5	17.37**
(C_1+C_2) vs C_3	1	665.0	665.0	0.47
$(C_1+C_2+C_3)$ vs C_4	1	251,398.9	251,398.9	177.89**
A x C	24	178,667.0	7,444.5	5.27**
Error	36	50,874.5	1,413.2	
Total	71	1,360,690		

**Significant at P = 0.01.

Table 10 - Mean values for specific surface of nine clays [illegible]

Clay	Treatment original
	--M^2/g--
1	213 d**
2	341 c
3	36[illegible] bc
4	414 bc
5	473 b
6	377 bc
7	364 bc
8	268 cd
Wy. bent.	697 a

**Entries followed by the same letter are not significantly different at P = 0.01

(Table 11) showed that there were significant decreases in specific surface of clays 2, 7, and Wyoming bentonite. The specific surface of these clays, expressed as M^2 per g, decreased from 34 to 220 for clay 2, from 364 to 192 for clay 7, and from 697 to 483 for Wyoming bentonite. The specific surface of clay 6 increased from 377 to 478 M^2 per g, while the specific surface of all other clays remained unchanged. The significant decrease in specific surface of clays 2, 7, and Wyoming bentonite was attributed to hydroxy Al partially blocking the interlayer surfaces from penetration by the ethylene glycol. Alternatively, poorly crystalline or amorphous materials were removed having a high specific surface. The increase observed in specific surface of clay 6 was probably the effect of removal of materials having a low specific surface.

Effect of 0.5 N NaOH

From the analysis of variance for specific surface (Table 9) there was not a significant interaction between clays and the effect of NaOH dissolution, when averaged over all clays. When the interaction within clays was examined (Table 12) the specific surface of clays 2 and 7 significantly increased after dissolution with 0.5 N NaOH compared to the average of the first two treatments. These increases as M^2 per g were from 28 to 359 for clay 2 and from 278 to 352 for clay 7. Clays 4, 5, and 8 significantly decreased in surface upon dissolution with 0.5 N NaOH. These decreases as M^2 per g were from 404 to 279 for clay 4, from 462 to 380 for clay 5, and from 288 to 210 g for clay 8.

Effect of acid NH_4F

From the analysis of variance (Table 9) for specific surface

Table 1.--Mean values for specific surface of nine clays before and after treatment with Na dithionite-citrate

Clay	Treatment: Original (C_1)	Treatment: After dithionite citrate (C_2)	'F' values
	M^2/g		
1	213	172	1.19
2	341	220	10.36**
3	361	339	0.33
4	414	393	0.31
5	473	451	0.34
6	377	478	7.29*
7	364	192	20.81**
8	268	309	1.19
Wy. bent.	697	483	32.56**

*Significant at P = 0.05.

**Significant at P = 0.01.

Table 12.--Mean values for specific surface of nine clays before and after treatment with 0.5 N NaOH

Clay	Treatment: Original + dithionite-citrate (C_1+C_2)	Treatment: After 0.5 N NaOH (C_3)	'F' values
	m^2/g		
1	192	235	1.74
2	281	359	5.81*
3	350	402	2.57
4	404	279	14.63**
5	462	380	6.34*
6	427	379	2.20
7	278	352	5.13*
8	288	210	5.81*
Wy. bent.	590	609	0.33

*Significant at P = 0.05.

**Significant at P = 0.01.

after treatment with acid NH_4F, a significant interaction existed for the effect of this treatment on the clays. Examination of this interaction (Table 13) revealed that after acid NH_4F, compared to the average of the first three treatments, the specific surface of all clays significantly decreased with the exception of soil clay 6. The specific surface, expressed in M^2 per g, of these clays when compared with the clays before the acid NH_4F decreased from 206 to 19 for clay 1, from 307 to 215 for clay 2, from 367 to 133 for clay 3, from 362 to 214 for clay 4, from 434 to 292 for clay 5, from 302 to 115 for clay 7, from 262 to 99 for clay 8, and from 596 to 484 for Wyoming bentonite. The specific surface of clay 4 was not significantly changed by the last treatment. Extractable Al in NH_4OAc (Appendix Table 47) after treatment of these clays indicates that these decreases are probably either blocking of interlayer spaces by AlF_3 or that disintegration of clay occurred with this treatment resulting in loss of surface.

Relationship between CEC and Specific Surface

Two positive, significant relationships were found between the CEC at pH 4.8 and 8.2 and specific surface (Fig. 4). The relationship between CEC at pH 4.8 and specific surface was as follows

$$Y = 34.54 + 5.54\ X \qquad [8]$$

where Y is the specific surface expressed in M^2 per g and X is the CEC expressed in meq per 100 g. The relationship between CEC at pH 8.2 and specific surface was as follows

$$Y = 37.43 + 4.52\ X \qquad [9]$$

Table 13 --Mean va ues for specif c surface of c ays before and after treatment with acid NH_4F

C ay	Treatment: Origina + d thionite-citrate + NaOH(C_1+C_2+C_3)	Treatment: After ac d NH_4F (C_4)	'F' values
1	206	139	8.09**
2	307	215	8 91**
3	367	133	58.45**
4	362	214	23 40**
5	434	292	2 45**
6	411	350	3.97
7	302	115	37.45**
8	252	99	28. 4**
Wy. bent.	596	484	13.31**

**Sign ficant at P = 0.01.

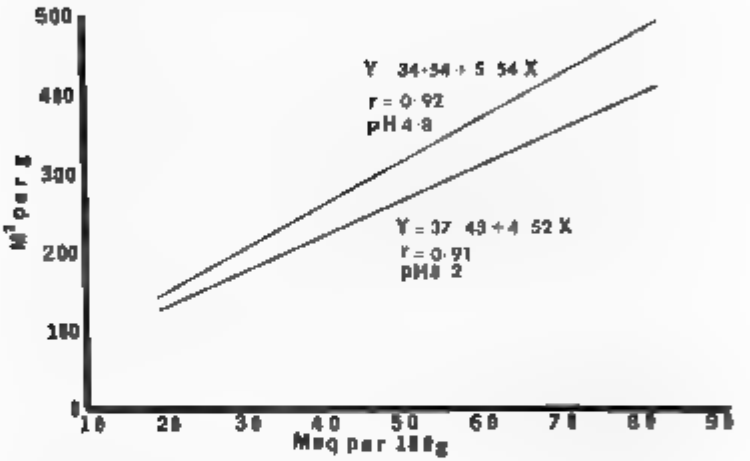

Fig. 4.--Relationships between all surface areas and CEC values.

where Y is the specific surface expressed in M^2 per g and X is the CEC expressed in meq per 100 g at pH 8.2. Regression equations [8] and [9] accounted for 85 and 83% of the observed variation, respectively. These relationships were interpreted to mean that the specific surface available for glycol retention was closely associated with the total sites available for CEC.

Nature of Materials Removed

Amount of materials removed

Material removed (Table 14) ranged from 24.4% for clay 2 to 52.8% for clay 6. A loss of 28.71% was recorded for Wyoming bentonite. These losses are assumed to be amorphous or poorly crystalline materials which were selectively dissolved by the sequential dissolution sequence employed. The effect of removal of the amorphous materials on specific surface and CEC is shown in Fig. 5. The area between the curves, based on original weight and the actual weight after treatments, reflects the contribution of amorphous material on both CEC and specific surface of these soil clays.

Composition of materials removed

Na dithionite-citrate extracts.--The concentrations of Si, Al, and Fe, expressed in the oxide form, removed by the Na dithionite-citrate are shown in Table 4. Treatment with this dissolution step primarily removes free iron oxides (1, 62, 67, 91). This is shown by the large amount Fe_2O_3 removed which ranged from 69.9 to 169.3 mg per g for soil clays while only 7.0 mg per g were found in the Wyoming bentonite clay extract. The large amounts of Fe and the comparatively small amounts of Si removed were reflected in the SiO_2 R_2O_3 molar ratios which ranged from 0.07 to 0.37 for soil clays and .17 for

Table 14.--Effect of sequent a d sso ut on on the amount and composition of 'amorphous materia s removed by sequent,al dissolution steps

Clay	Composition of materials removed								Total weight loss at 105C
	SiO_2	A_2O_3	Fe_2O_3	MgO	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$	$\frac{R_2O_3}{MgO}$	
	mg/g								
				Na dithionite-citrate (I)					
1	5.7	24.0	169	-	0.41	0.07	0.09	-	-
2	7.8	19.7	101	-	0.68	0.16	0.13	-	-
3	9.6	42.7	64	-	0.37	0.20	0.43	-	-
4	8.0	16.1	122	-	0.85	0. 4	0.08	-	-
5	12.3	13.6	70	-	1.53	0.37	0.12	-	-
6	8.0	24.4	138	-	0.66	0.12	0..0	-	-
7	11,8	17.7	131	-	1.14	0.20	0.09	-	-
8	9.5	21.5	132	-	0.75	0.15	0.10	-	-
Wy. bent.	4.3	1.7	7	-	4.30	1.17	0.15	-	-
				0.5 N NaOH (II) + Na dithionite-citrate (III)					
1	358	96.7	12.6	-	6.29	5.80	4.91		-
2	363	79.7	22.1	-	7.70	6.58	2.31		-
3	259	74.4	8.4	-	5.92	5.54	5.67		-
4	261	44.9	23.1	-	9.86	7.50	1.24		-
5	204	40.2	8.4	-	8.64	7.73	3.07		-
6	196	28.3	5.1	-	11.73	10.55	3.55		-
7	402	88.2	23.5	-	7.75	6.63	2.40		-
8	288	79.7	19.0	-	6.12	5.33	2.68		-
Wy. bent.	89	8.6	1.2	-	17.68	16.56	4.59		-

Table 14.--Continued

Clay	Composition of materials removed								Total weight loss at 105C
	SiO_2	Al_2O_3	Fe_2O_3	MgO	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$	$\frac{R_2O_3}{MgO}$	
	----------mq/g----------								
				Acid NH_4F (IV)					
1	34.5	38.7	7.4	1.49	1.68	1.49	3.33	10.8	-
2	64.3	47.5	26.6	5.72	2.30	1.67	1.15	4.6	-
3	46.0	41.8	3.6	0.83	1.87	1.79	7.42	21.5	-
4	45.4	37 8	4 7	2.16	2.04	1.90	5. 2	8.0	-
5	61.6	45.3	32.8	1.82	2.31	1.58	0.88	13.0	-
6	53.5	38.3	17.9	1.82	2.38	1.82	1.36	9.8	-
7	76.7	58.3	30.7	6.55	2.24	1.68	1.22	4.8	-
8	57.6	44.2	23.5	4.06	2.21	1.66	.20	5.9	-
Wy. bent.	13.5	13.3	0.6	0.33	1.72	1.77	14.08	13.0	-
				Total					
1	402	162	189	1.49	4.22	2.93	0 54	-	52 85
2	435	147	149	5.72	5.03	3.06	0 63		33 98
3	315	159	76	0.83	3.37	2.57	34	-	37 44
4	315	89	150	2.16	6.02	2.90	0 38		47 37
5	278	99	111	1.82	4.76	2.79	0 60	-	27 89
6	257	87	166	1.82	5.03	2.26	0 33	-	24.42
7	490	164	185	6.55	5.07	2.95	0.60	-	36 07
8	355	145	174	4.06	4.17	2.36	0 53	-	37 93
Wy. bent.	108	24	8	0.33	7.65	6.21	1 92	-	28.7

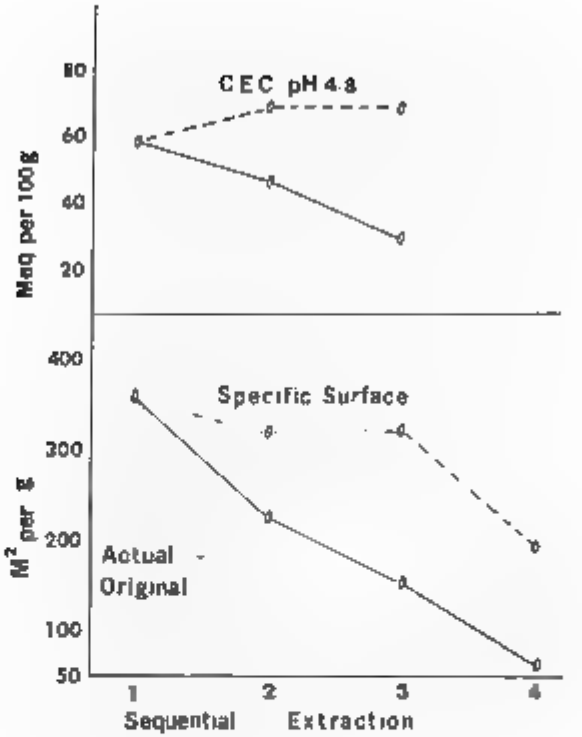

Fig. 5.--Mean effect of treatment on CEC and specific surface where sequential extraction 1 is untreated clay, 2 is dithionite-citrate, 3 after 0.5 N NaOH, and 4 after acid NH_4F. The dotted line refers to measurements based on clay weight after treatment and solid line on original clay weight.

Wyoming bentonite. McKeague and C line (86) have found that some of the amorphous s l ca in soils occurs as coatings at the surface of iron oxides. This could easily account for the small amounts of Si found in this extract. The concentrat on of Al ranged from 13 6 to 43 5 mg per g of materia removed compared to 1.7 mg per g for Wyoming bentonite. The Al_2O_3 Fe_2O_3 mole ratios ranged from 0.08 to 0 43 compared to 0.15 for Wyoming bentonite.

Extracts from treatment with 0 5 N NaOH.--The 0.5 N NaOH + Na d thion te-citrate d ssolut on step (Table 14) removed large quantities of SiO_2 which ranged from 96 to 402 mg per g, for so l clays compared to only 89.8 mg per g removed from wyom ng bentonite. The amount of Al expressed as A_2O_3 removed was less than for SiO_2, but more than Fe_2O_3 after these treatments. These values were ref ected in the SiO_2 Al_2O_3 mo e ratios which ranged from 5.92 to 1.73 for the soil c ays compared to 17.68 for wyom ng bentonite. The SiO_2 R_2O_3 mo e ratios ranged from 5.33 to 10.55 for soil clays while it was 16.56 for Wyoming benton te. The A_2O_3 Fe_2O_3 mo.e ratios ranged from 1.24 to 5.67 for soil clays compared to 4.59 found for Wyom ng bentonite. The h gh SiO_2 Al_2O_3 and SiO_2 R_2O_3 mole ratios indicate that the amorphous materials removed were not allophanic in nature, but phyllosi icate relics, criteria for which were given by Jackson (65, 67).

Extract from acid NH_4F.--The acid NH_4F dissolution step removed Si, Al, Fe, and Mg (Tab e 14) The relative amounts of SiO_2 and Al_2O_3 were ref ected in the SiO_2 Al_2O_3 mo e rat os which ranged from 68 to 2.38 for so clays and was 1.72 for Wyoming bentonite. The relative amounts of SiO_2 and R_2O_3 were about 1.7 as reflected by the SiO_2-R_2O_3 ratios ranging from 1 49 to .90 for so l clays compared to

1.77 for Wyoming bentonite. The $Al_2O_3.Fe_2O_3$ mole ratios ranged from 0.88 to 7.42 in the soil clays as compared to 4.08 for Wyoming bentonite. These ratios indicated that the soil clays have larger amounts of combined iron possibly occupying octahedral positions. Also MgO was found to be prevalent indicating either the presence of chlorite, Mg silicate, or a poorly crystalline Mg-rich montmorillonite (105, 133). Rich (105) has noted in particular, that Mg-rich montmorillonite is destroyed in 24 to 48 hrs at room temperature by acid NH_4F

Total extracts.--The composition of the total material removed was quite consistent for the soil clays. The SiO_2 Al_2O_3 mole ratios for soil clays ranged from 3.37 to 6.02 for soil clays indicating that the amorphous materials were siliceous. The SiO_2 R_2O_3 mole ratios ranged from 2.26 to 3.06 showing that the material was siliceous in nature even when free iron oxides were included in the calculations. The mole ratio for Wyoming bentonite decreased from 7.65 for the SiO_2 Al_2O_3 mole ratio to 6.21 for the SiO_2 R_2O_3 mole ratio. The Al_2O_3 Fe_2O_3 mole ratios for the soil clays ranged from 0.33 to 1.34 indicating that more total Fe than Al was removed by these treatments. Further discussion of these data are presented in a later section dealing with the effect of amorphous removal on X-ray diffraction, infrared, and DTA patterns of these clays.

Clay-Mineralogy

X-ray diffraction patterns

X-ray diffraction patterns were used for characterization of the crystalline minerals in the clay fraction of the eight soils used in the study. Three patterns were run for each clay including the original

clay and residual clay after each of the sequential dissolution steps. These patterns were for clay that was Mg saturated and glycerol solvated, clay that was K saturated, and clay that was K saturated and then heated gradually to 550C. From previous research (65), kaolinite was identified from the first order diffraction spacing at 7.2 A, the second order spacing at 3.57 A, and by disappearance of these spacings after heating to 550C. Halloysite was identified after glycol solvation by the first order spacing at 10.8 A and the third order spacing at 3.66 A. Metahalloysite was suggested by 7.2- to 7.5-A spacings after K saturation and by disappearance of these spacings after heating to 550C. Quartz was identified from the 4.21- and 3.35-A spacings. Chlorite was sought by the spacing at 14 to 15 A and any intensification of the 7.2-A spacing after heating at 550C. Chlorite was not found in any of the X-ray diffraction patterns studied. Vermiculite was identified by the 14- to 15-A spacing and a 9.9- to 10.1-A spacing after heating to 550C. Mica was concluded to be present from 9.9- to 10.1-A spacings observed. Cristobalite was identified by a 4.05-A spacing. Gibbsite which has a 4.34-A spacing was not found. Montmorillonite was sought from the 18-A spacing and the 8.85- and 4.45- to 4.60-A spacing after Mg saturation. It was confirmed by the 2.4- to 2.8-A spacing with K saturation, and the 9.9- to 10.4-A spacing after heating to 550C. A $1/6^{\circ}$ divergence slit was used for scanning between 44.13 and 11.04 A to cut down background scatter from monochromator and still use a sensitivity of x2x50 counts per second which facilitated the detection of montmorillonite, at the 18-A spacing, and of interstratified mixtures. A 1° divergence slit was used for scanning between 17 and 3 A.

The crystall ne portion of the clay fract on of the 4 soil c ays generally gave very weak X ray diffraction patterns (F g 6). Small crystal s ze of the phy os l cates (Z ax s lim tat on) wh ch was ndictive of partic e size under 0.02 microns or poor y crystal ne mater a s approach'ng an amorphous material (65) was apparently dominant in these patterns. The smal particle s ze or poor y crys- ta line nature of the soil clays is indicated n figures 6, 7, 8. The correspond ng spacings are listed in Append x Table 52. These patterns show l ne broader ng and a broad plateau from 10 to 8 A with smal d fferential peaks. The commonly strong peak at 3 5 A was the combined suborder of severa other spacings. These were as fo ows 002) of 7 A, (003) of 0 A, (004) of 4 A, and (005) of 18 A. THIs s another symptom of Z-axis l mitation ndicating sma l phyl os l cate particle size. General y very weak patterns were observed for the orig na c ays. The intensit es of the peaks improved s ghtly after sequentia dissolution with dithion te citrate and 0.5 N NaOH. A decrease in kaolin te m nerals and a ncrease in quartz was generally observed after dissolution with the acid NH_4F reagent.

The crystallinity of soil clay l from Patino is shown in Figs. 6 and 7 and data n Tab e 15. Th s c ay was composed pr mar y of l phyl osil cates wh ch were ha oys tic in nature although smal er amounts of interstratif ed m xtures of montmor lonite and verm cu lite, cristobalite, and quartz were observed.

Soil c ay 2 from Yev za (F gs 6 and 8 and Table 15) consisted primari y of interstratif ed mixtures of montmor llon te and verm cu- llte which gave d/n spacings of 32 A for glycerol solvation and 10 A after heating to 550C. Also smal er amounts of montmor lonite, vermiculite, halloysite, and quartz were detected in these patterns.

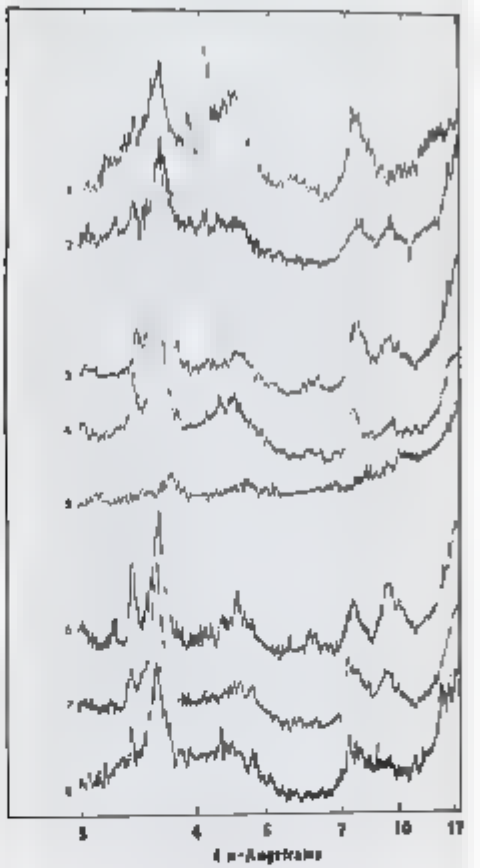

Fig. 6.--X-ray diffraction patterns of Mg-saturated soil clays after the 0.5 N NaOH in the sequential dissolution steps. The inset numbers are as follows: (1) soil clay 1; (2) soil clay 2; (3) soil clay 3; (4) soil clay 4; (5) soil clay 5; (6) soil clay 6; (7) soil clay 7; and (8) soil clay 8.

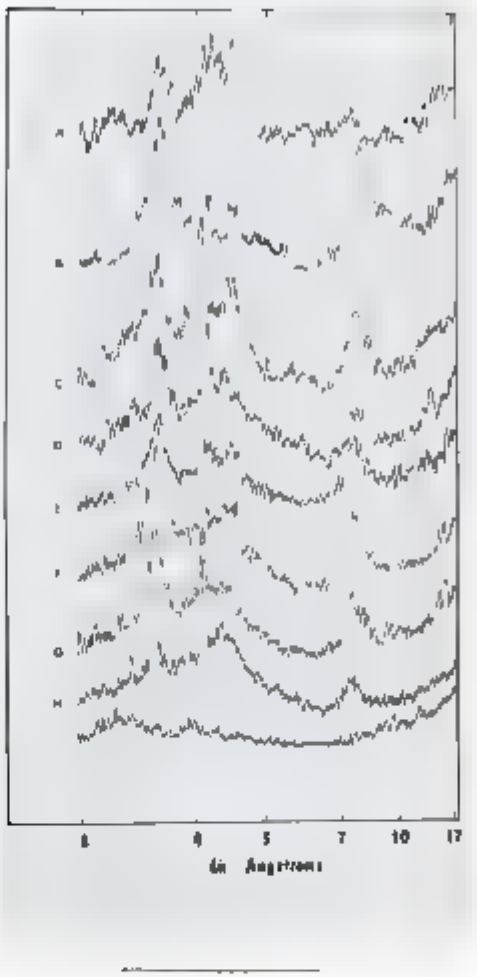

Fig. 7--X-ray diffraction patterns of soil clay 1 after sequential treatment. The inset letters are as follows: (A) Mg-saturated, glycerol-solvated clay before treatment, (B) Mg-saturated, glycerol-solvated clay after dithionite-citrate; (C) Mg-saturated, glycerol-solvated clay after 0.5 N NaOH; (D) Mg-saturated, glycerol-solvated clay after acid NH_4F; (E) K-saturated clay before ; (F) K-saturated clay after dithionite-citrate, (G) K-saturated clay after 0.5 N NaOH; (H) K-saturated clay after acid NH_4F treatment, and (I) K-saturated, heat-treated clay before treatment.

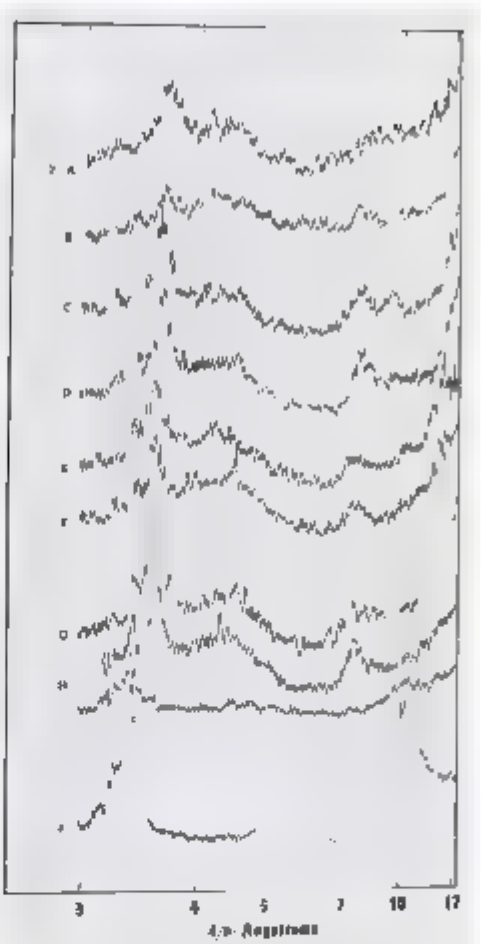

Fig. 8.--X-ray diffraction patterns of soil clay 2 after sequential treatment. The inset letters are as follows: (A) Mg-saturated, glycerol-solvated clay before treatment, (B) Mg-saturated, glycerol-solvated clay after dithionite-citrate; (C) Mg-saturated, glycerol-solvated clay after 0.5 N NaOH; (D) Mg-saturated, glycerol-solvated clay after acid NH_4F, (E) K-saturated clay before treatment, (F) K-saturated clay after dithionite-citrate; (G) K-saturated clay after 0.5 N NaOH; (H) K-saturated after acid NH_4F, (I) K-saturated, heat-treated clay before treatment; and (J) K-saturated, heat-treated after 0.5 N NaOH

Table 5 -Crystalline minera s recogn zed from X-ray d ffract on patterns of soil clays from eastern Panama

Clay No.	Location	Crystalline minerals+
1	Patino	K_1 M/V_3 Cr_3 Q_3
2	Yeviza	M/V_1 M_3 V_3 K_3 I_3 Q_3
3	Santa Fe	V/I_1 M/V_1 M/I_1 K_3 Q_3
4	Trocha	V/I_1 M/V_1 M/I_1 K_2 Q_3
5	Rio Sabana	V/I_1 M/V_1 M/I_1 K_3 Q_3
6	Rio Lara	M_1 M/V_1 M/I_1 K_2 Q_3
7	Rio Chucunaque	M_1 V_1 M/V_1 K_2 Q_3
8	Rio Chico	V_1 V/I_2 K_3 Q_3

+Because of the poorly crysta ine nature of these so l clays a sensitivity of 1x2x50 was utilized

K = Kaol nite or halloysite

M = Montmor llonite

V = Vermicul te

I = Ill te

Cr = Cristobal te

Q = Quartz

The smal numerals ind cate the re at ve intensities w th 1 be ng the highest, 2 intermediate and 3 the lowest.

Soil clay 3 from Santa Fe (Fig. 6 and Table 5) gave patterns similar to those observed for soil clay 2 with the exception that some interstratified mixtures of vermiculite, illite, and montmorillonite were presumed to be present from the additional broad peaks observed for d/n spacings between 20 and 25 A. Smaller amounts of halloysite and quartz were also noted in these patterns.

Soil clay 4 from Trocha yielded patterns suggesting some presence of interstratified mixtures of vermiculite and illite, montmorillonite and vermiculite, and montmorillonite and illite (Fig. 6 and Table 5). Halloysite and quartz were also found in smaller quantities.

Soil clay 5 from Rio Sabana (Fig. 6 and Table 5) contained approximately the same minerals as were observed in soil clay 3. These were interstratified mixtures of vermiculite and illite and of montmorillonite and illite. Smaller quantities of halloysite and quartz were also present.

The crystalline fraction of soil clay 6 from Rio Lara (Fig. 6 and Table 15) was composed primarily of montmorillonite and illite although halloysite and quartz were present to a lesser degree.

Soil clay 7 from Rio Chucunaque contained crystalline minerals similar to those found in soil clay 6 with the exception that vermiculite was present as indicated by the 14- to 15-A spacing after Mg saturation and glycerol solvation. Evidence for the presence of illite was not found.

Soil clay 8 from Rio Chico (Fig. 6 and Table 15) was primarily poorly crystalline vermiculite as indicated by the 14- to 15-A peak with some interstratified vermiculite and illite also present. In all of these clays a strong 3.5-A peak intensity was found which would

indicate the presence of small particle size kaolinites illites, vermiculites, and montmorillonites either singly or in combinations In many instances these peaks could not be analyzed because of a plateau effect.

Differential thermal analysis

In this study, the endothermic patterns were unique in that the original clay and the clay after three sequential dissolution treatments were run simultaneously. This made uniform conditions for evaluating changes which occurred after sequential dissolution This was also enhanced by having the clays previously desiccated to the same degree by drying at 40C. The values presented in Table 16 were obtained by tracing the patterns and cutting out the endothermic area which was weighed. Since allophane, hydrated halloysite, vermiculite, and montmorillonite all release water in the region from 55 to 250C (44, 65), in this study endotherms in this region are referred to as the low-temperature endotherms. Kaolinite and halloysite have endothermic peaks from 525 to 600C and are referred to as the high-temperature endotherms. Use of the slope ratio of the endothermic peak sides as an index of presence of kaolinite or halloysite was made in light of work by Bramao et al (21), Dean (30), and Fiskell and Caris e (44) The terms a and b (Table 16) represent the tangents to the angles made with the side of the high-temperature peaks

With few exceptions in these clays, the peak area of the low-temperature endotherms (Figs. 9 10, 11, 12 and Table 16) was highest after removal of free iron oxides with the exception of soil clay I Probably, the dithionite-citrate reagent removed material less hydrated than that remaining in the clay The treatment of clays

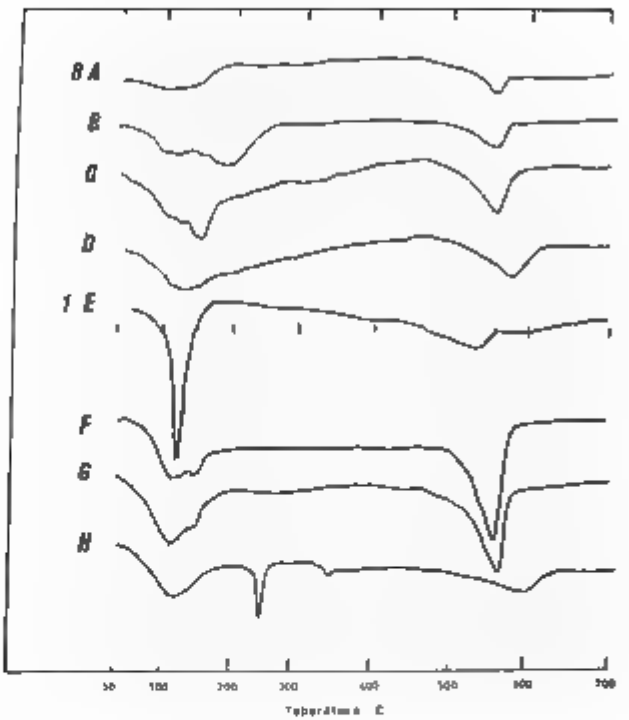

Fig. 9.--Differential thermal patterns of soil clays 8 and 1 after sequential treatment. The inset letters are as follows: (A) soil clay 8 before treatment, (B) soil clay 8 after dithionite-citrate; (C) soil clay 8 after 0.5 N NAOH, (D) soil clay 8 after acid NH_4F; (E) soil clay 1 before treatment; (F) soil clay 1 after dithionite-citrate, (G) soil clay 1 after 0.5 N NaOH; and (H) soil clay 1 after acid NH_4F.

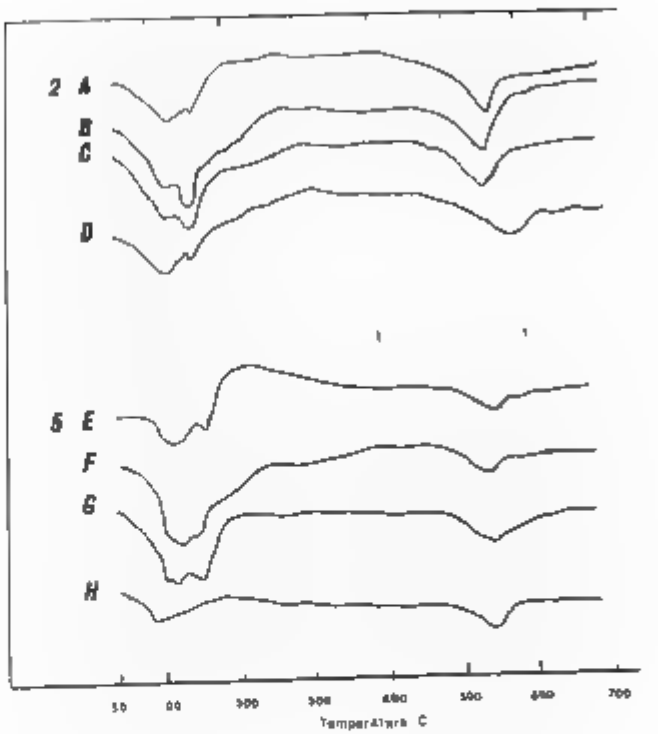

Fig. 10.--Differential thermal patterns of soil clays 2 and 5 after sequential treatment. The inset letters are as follows: (A) clay 2 before treatment; (B) clay 2 after dithionite-citrate; (C) clay 2 after 0.5 N NaOH; (D) clay 2 after acid NH_4F; (E) clay 5 before treatment; (F) clay 5 after dithionite-citrate, (G) clay 5 after 0.5 N NaOH; and (H) clay 5 after acid NH_4F.

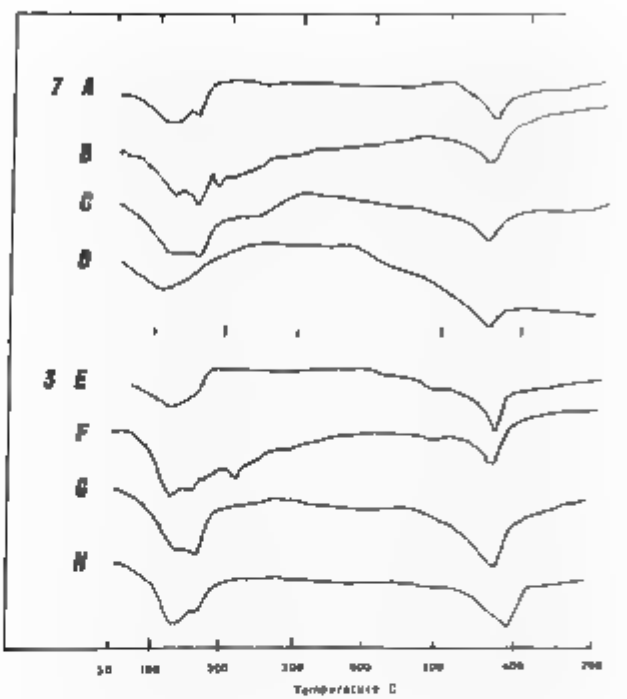

Fig. 11.--Differential thermal patterns of soil clays 7 and 3 after sequential treatment. The inset letters are as follows: (A) clay 7 before treatment; (B) clay 7 after dithionite-citrate; (C) clay 7 after 0.5 N NaOH; (D) clay 7 after acid NH_4F; (E) clay 3 before treatment; (F) clay 3 after dithionite-citrate, (G) clay 3 after 0.5 N NaOH;and (H) clay 3 after acid NH_4F.

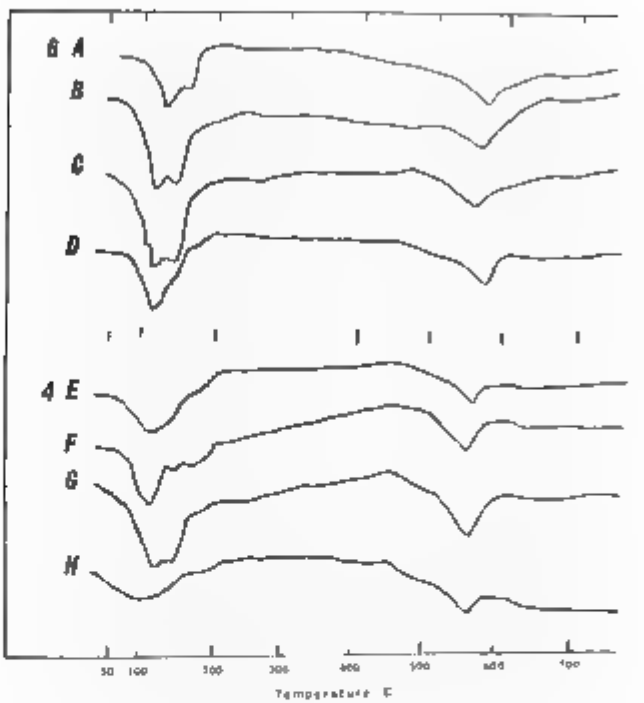

Fig. 12.--Differential thermal patterns of soil clays 6 and 4 after sequential treatment. The inset letters are as follows: (A) clay 6 before treatment; (B) clay 6 after dithionite-citrate; (C) clay 6 after 0.5 N NaOH; (D) clay 6 after acid NH_4F; (E) clay 4 before treatment; (F) clay 4 after dithionite-citrate; (G) clay 4 after 0.5 N NaOH, and (H) clay 4 after acid NH_4F.

Table 16.--Differential thermal analysis of some reference minerals and soil clays after sequential treatments

Sample		Endotherms				
		Low temperature		High temperature		
		Peak area	Peak temp. max.	Peak area	Peak temp. max.	1:1 layer lattice peak shape
		cm^2	°C	cm^2	°C	a/b
Halloysite			120	11.6	563	2.20
Kaolinite			100	12.9	586	1.38
Wy. bent.	A+	7.8	135	3.4	705	
	B	8.7	140	5.5	700	
	C	7.1	149	5.3	710	
	D	8.4	135	2.8	725	
Clay 1	A	9.8	118	1.2	540	4.47
	B	4.8	120,144	9.2	564	3.74
	C	12.8	116,150	6.6	560	4.00
	D	4.5	116	2.2	600	2.53
Clay 2	A	6.1	124,154	3.2	564	2 45
	B	13.2	116,150	4.6	560	3 37
	C	9.6	116,150	3.6	560	2 38
	D	3.1	116,150	2.4	586	09
Clay 3	A	4.9	116	1.2	540	4 47
	B	11.9	120,145	9.2	564	3.74
	C	5.5	124,145	6.6	560	4.00
	D	5.7	124	2.2	600	2 53
Clay 4	A	10.7	116	2.4	558	2.07
	B	12.6	116	4.2	550	67
	C	8.1	124	4.6	557	76
	D	3.7	100	2.2	566	1 05
Clay 5	A	6.3	114,150	1.8	560	1.73
	B	3.7	125,142	1.6	550	0.72
	C	8.8	125,150	3.0	560	1 14
	D	3.1	100	1.6	560	76

Tab e 16.--Continued

Sample	Endotherms				
	Low temperature		High temperature		
	Peak area	Peak temp. max.	Peak area	Peak temp. max.	1.1 layer lattice peak shape
	cm^2	^oC	cm^2	^oC	a/b
Clay 6 A	6.9	115,150	2.6	565	1.33
B	7.2	115,150	3.3	557	1.91
C	10.6	115,145	2.9	555	1.10
D	5.7	120	2.3	570	1.63
Clay 7 A	8.2	116,150	3.3	557	1.26
B	17.8	116,146	4.6	550	2.28
C	9.0	116,150	3.4	550	2.00
D	1.7	108	2.5	564	1.81
Clay 8 A	3.1	100	3.0	560	1.60
B	18.2	120,185	3.2	550	2.94
C	4.0	125,150	3.9	559	2.16
D	3.5	120	4.0	578	1.69

+Symbol A, refers to untreated c ay, B to clay after d thion te- c trate treatment, C to clay after treatment with 0 5 N NaOH fol owed by citrate-d thion te reagent, and D to c ay after treatment with acid NH_4F.

with 0.5 N NaOH decreased the low-temperature endotherms found in soil clays 2, 3, 4, 7, and 8, but the opposite occurred for soil clays 1, 5, and 6. Treatment of the clays with acid NH_4F generally resulted in a decrease of the low temperature endothermic area. The low-temperature endotherms generally showed doublets (Figs. 9, 10, 11, 12) for the original clay and after the first two dissolution steps, with the exception of soil clay 4. This doublet corresponds to the low-temperature endotherms found for halloysite at 120C and that for montmorillonite at 140 to 190C (44, 65). The low-temperature endotherm at approximately 145C disappeared in all cases after this treatment with the exception of soil clay 1. Rich (105) has noted that after use of acid NH_4F for 24 hrs, Mg-rich montmorillonite is destroyed. Fine-particle size would facilitate this destruction.

The shape of the high-temperature endotherms between 560 to 580C (Figs. 9, 10, 11, 12 and Table 16) suggested that these soil clays contain halloysite or in some cases mixtures of halloysite and kaolinite. The most distinct halloysite peak was found in soil clay 3 where a slope ratio of 3.74 was noted after treatment with dithionite-citrate (Fig 9 and Table 16). Treatment with acid NH_4F generally decreased the peak areas and in soil clays 1, 2, 4, 7, and 8 there was also a change in peak shape (Figs 9, 10, 11, 12 and Table 16).

The DTA patterns of these soils (Figs. 9, 10, 11, 12) further confirmed findings by X-ray diffraction that gibbsite was not present. Gibbsite, $Al(OH)_3$, gives a strong endotherm at 330-350C, of sufficient magnitude to permit detection of as little as 1% of this mineral (65) thus indicating that little or no gibbsite was present in these soil clays. Also the DTA patterns indicate that the intense 3.5-A spacing

n the X-ray diffract on patterns are probably a combination of ha loysite and montmor llonite w th the exception of soil clay 4

Infrared analysis

In th s study infrared data were used to support evidence obtained from studies of these clays by X-ray diffract on and DTA. Also, these c ays were examined by infrared for the effect of the sequential disso utions. The infrared spectras of the original clay (Figs 13, 14, 15, 16), show absorption bands typical of 1:1 and 2:1 clay minerals (Fig. 17). Infrared-absorption spectras similar to those of allophane shown by Mejia et a , (92) were absent. Al the spectras of the original soil c ays show large absorption bands between 3,900 and 2,800 cm⁻ This absorption band is attributed to a combination of free O-H stretch at 3,700 cm^{-1}, plus stretching vibration of the free O-H groups of the octahedral layer of the clay minerals at 3,600 cm^{-1}, and the stretching vibration in bonded O-H groups associated with adsorbed water on clay surfaces at 3,450 cm^{-1} (81, 95). The absorption peaks at 3,450 cm^{-1} in these clays are attributed either to hal oysite or water associated with nternal surfaces of an expanded 2: -layer silicate. This is also observed in the standard clay samples (Fig. 7) where halloysite and montmorillon te a so show a relatively large absorption band at this frequency compared to kaolin te. The absorption band at 1,634 cm^{-1} was observed in all the clay fract ons. This is H-O-H bending (81, 95).

The absorption band between 1,250 and 961 cm⁻ is a Si-O vibration found in silicate clay minerals (78, 81, 95). The absorption band at 910 cm⁻ found in soil clays 1, 3, 4, and 7 are indicative of a X^{+3}-O-H bending vibration which could ind cate e ther d octahedral com-

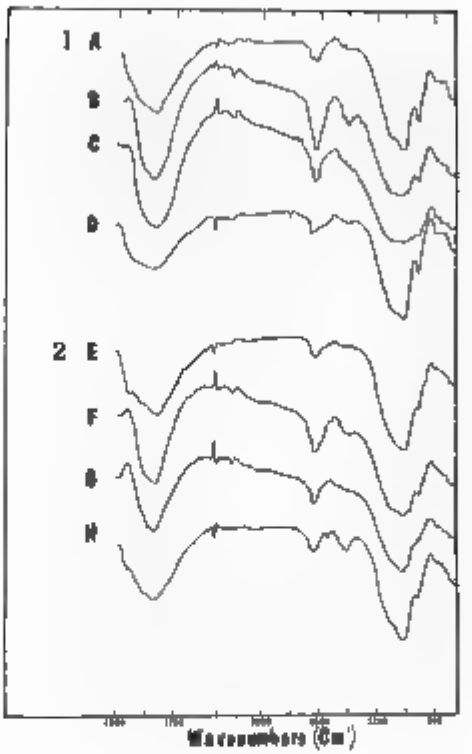

Fig. 13.--Infrared spectra of soil clays 1 and 2 after sequential treatment. The inset letters are as follows: (A) clay 1 before treatment; (B) clay 1 after dithionite-citrate; (C) clay 1 after 0.5 N NaOH; (D) clay 1 after acid NH_4F; (E) clay 2 before treatment, (F) clay 2 after dithionite-citrate; (G) clay 2 after 0.5 N NaOH; and (H) clay 2 after acid NH_4F.

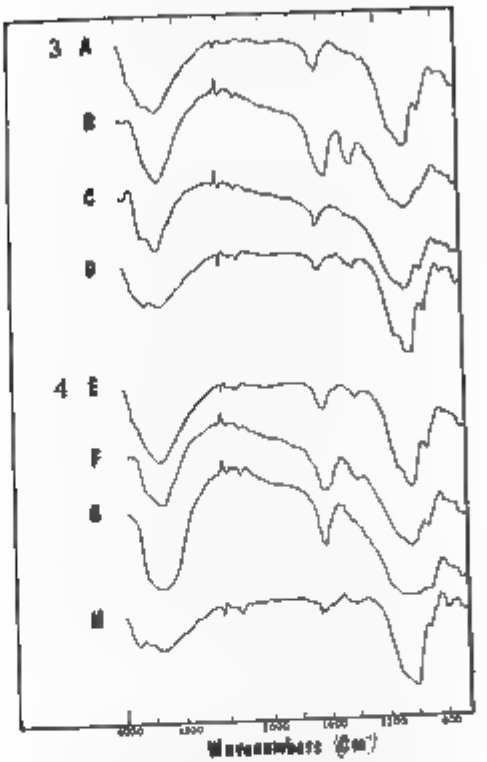

Fig. 14.--Infrared spectra of soil clays 3 and 4 after sequential treatment. The inset letters are as follows: (A) clay 3 before treatment, (B) clay 3 after dithionite citrate; (C) clay 3 after 0.5 N NaOH; (d) clay 3 after acid NH_4F; (E) clay 4 before treatment (F) clay 4 after dithionite-citrate, (G) clay 4 after 0.5 N NaOH; and (H) clay 4 after acid NH_4F.

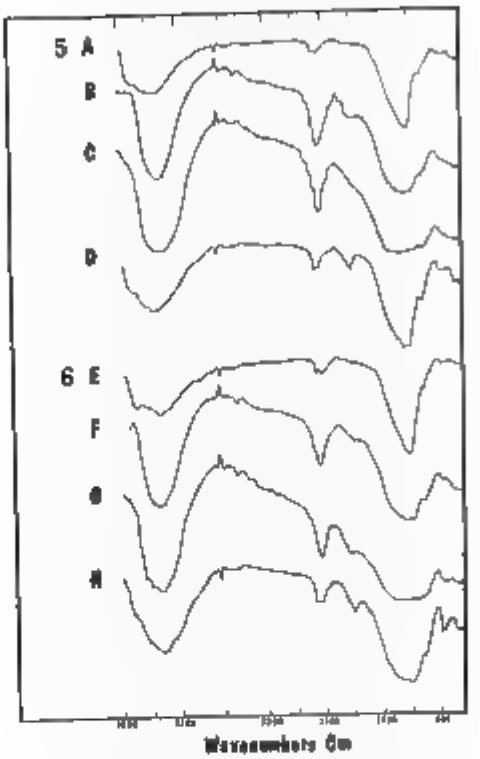

Fig. 15.--Infrared spectra of soil clays 5 and 6 after sequential treatment. The inset letters are as follows: (A) clay 5 before treatment; (B) clay 5 after dithionite-citrate, (C) clay 5 after 0.5 N NaOH, (D) clay 5 after acid NH_4F, (E) clay 6 before treatment, (F) clay 6 after dithionite-citrate, (G) clay 6 after 0.5 N NaOH; and (H) clay 6 after acid NH_4F.

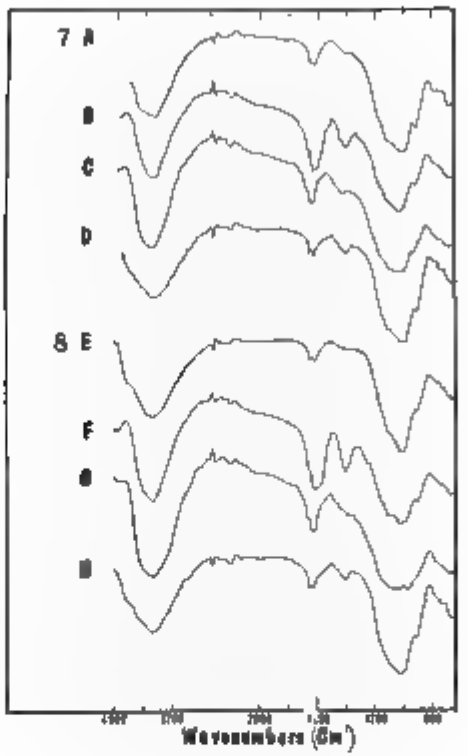

Fig. 16.--Infrared spectra of soils clay 7 and 8 after sequential treatment. The inset letters are as follows: (A) clay 7 before treatment, (B) clay 7 after dithionite-citrate; (C) clay 7 after 0.5 N NaOH; (D) clay 7 after acid NH_4F; (E) clay 8 before treatment, (F) clay 8 after dithionite-citrate, (G) clay 8 after 0.5 N NaOH, and (H) clay 8 after acid NH_4F.

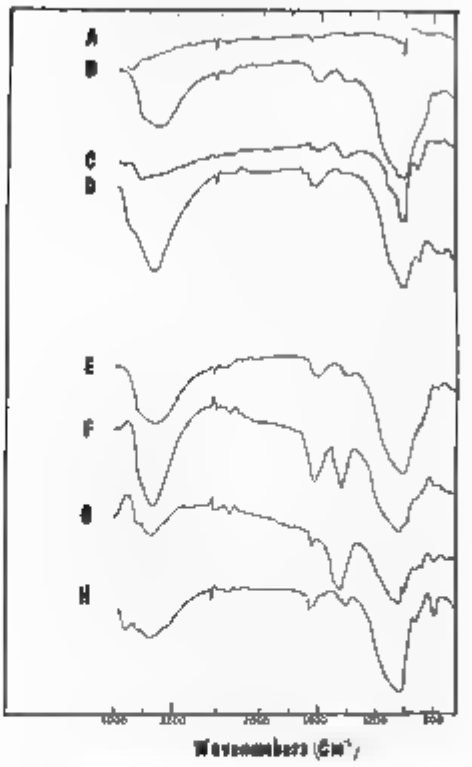

Fig. 17.--Infrared spectra of KBr blank and standard minerals. The inset letters are as follows: (A) KBr blank; (B) Ward's bentonite No. 25; (C) Ward's kaolinite No. 4; (D) Ward's halloysite No. 12, (E) Ward s bentonite No. 25 before treatment, (F) bentonite after dithonite-citrate treatment; (G) bentonite after 0.5 N NaOH treatment, and (H) bentonite after acid NH_4F treatment.

position for the 2:1 layer silicate or Al-O-H for kaolin minerals or both. From the evidence presented for X-ray diffraction and DTA this absorption band was assigned to halloysite. Mejia et al. (92) found a similar band for halloysite in soil clays from the Colombian Andes. It is observed (Fig. 13) that the 910 cm^{-1} absorption band for soil clay 1 is the most intense, further confirming the interpretation of X-ray diffraction and DTA that the primary mineral present in this soil clay is halloysite. Soil clays 2, 5, 6, and 8 (Figs. 13, 15, 16) show very little, if any, absorption at 910 cm^{-1} indicating that the amount of kaolinite minerals in these fractions are small. In all soil clay fractions, the characteristic absorption bands for quartz at 800 and 780 cm^{-1} were observed.

After treatment with dithionite-citrate an additional absorption band was observed at 1,410 cm^{-1}, Figs. 13, 14, 15, 16). A similar band at 1,430 cm^{-1} was observed by DeMumbrum and Chesters (32) which, they suggested, was a ferric silicate. In these clays, the absorption band at 1,410 cm^{-1} was attributed to the HCO_3^- absorption as listed by Cross (28). The reasons for assignment of this absorption band to HCO_3^- is that the dithionite-citrate dissolution step is buffered with $NaHCO_3$ and since citrate was used as the chelating agent precipitation as ferric silicate would be very unlikely. There was also an increase in the absorption band for Si-O vibrations. This was attributed to the concentrating of the phyllosilicates after removal of free Fe oxides. After treatment with 0.5 N NaOH there was another increase in the absorption band for Si-O vibrations (Figs. 13, 14, 15, 16) indicating that siliceous materials had been concentrated to an even larger extent. This would be expected since the material removed by

this dissolution was probably a combination of poorly crystalline material and hydroxy-aluminum polymers. After treatment with acid NH_4F the intensity of the Si-O absorption band was decreased (Figs. 13, 14, 15, 16) and the patterns were very similar to those observed for the original clays. The absence of SiF_6^{-2} after dissolution with acid NH_4F was confirmed by the absence of an absorption band at 830 cm^{-1} (28).

Root, Soil, and Leaf Analysis

Corn Root and Soil Analysis from Eight Locations in Eastern Panama

Effect of location on P in root extracts

Samples were taken from the locations shown in Figure 2 and briefly characterized in Appendix Table 53. Locations were designated as geographic areas containing similar soils, topography, and other physical features. Sites are referred to as the individual sample taken from within a particular location.

Root P.--Data for root extract P, which are summarized in Table 17, show significant differences between locations for root extracts IV. No detectable amount of P was found in extracts I or in the soil extracts using the same reagent. There was no significant difference in root P between locations. In root extracts II and III, P ranged from 16.3 to 62.4 ppm and from 42.3 to 62.2 ppm, respectively. Roots at location 12 contained a larger amount of P in extract IV, 124 ppm, than at location 5 with 61 ppm. At other locations P values in roots were not significantly different.

Effect of extraction on removal of root P

Root P.--Root extractions II and III removed significantly differ-

Tab e 17.- Mean P concentration extracted from soi s and ad,acent corn roots at eight locations

Location number	Sites	Soil extraction 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total
		ppm P				
5	5	0.0	0.0	18.5 a*	42.3 a	61 b
6	2	0.0	0.0	18.0 a	46.2 a	64 ab
7	4	0.0	0.0	54.7 a	62.2 a	92 ab
8	3	0.0	0.0	16.7 a	49.5 a	66 ab
9	6	0.0	0.0	54.5 a	56.9 a	81 ab
11	2	0.0	0.0	16.3 a	58.7 a	75 ab
12	4	0.0	0.0	62.4 a	61.8 a	124 a
13	2	0.0	0.0	52.1 a	50.8 a	103 ab
Mean		0.0	0.08	36.7 e	53.6 d	83

* Entries fol owed by the same letter (a, b, or c) vert cally and (d, e, or f) hor zontally, are not different significantly at P = 0 05. Vertical comparisons are based on Duncan's method for mak ng comparisons between unequally replicated treatments, wh le horizontal comparisons are based on t' test for unpa red observations and unequal variances as described by Steel and Torrie (117). Means are based on 28 observations.

ent amounts of P (Table 7). Root extraction I 1 removed the largest amount of P, 53.6 ppm while root extract on I removed 36 7 ppm.

Effect of location on extractable root and soil K

Root K --Data for root K (Table 18) showed significant differences between locations within each step of root extraction At location 9 larger amounts of K in root extract I, 1 ppm, were found than at locations 5, 6, 11, 12, and 13 which ranged from 170 to 431 ppm. Locations 8 and 9 contained ,050 and 1,120 ppm of K in root extracts which were significantly more than those from locations 7, 11, 2, and 3 which ranged from 40 to 21 ppm. At location 6, significantly larger amounts of K were found in root extract III than at locations 5 1 , 12, and 3 which ranged from 145 to 490 ppm At location 9, larger amounts of K were obtained in root extract IV than from locations 5, 7, 11, 12, and 13 which ranged from 222 to 1,069 ppm

Soil K.--Soil-extract K (Table 18) was significantly larger at location 9 than those from locations 5, 6, 7, 8, 1 , and 2 which ranged from 170 to 431 ppm.

Effect of extraction on removal of root K

Root K. --Root extraction I (Table 18) removed significantly lower quantities of K than root extractions II and III. Extractions II and III removed 5 6 and 493 ppm of K, respectively, from the root which accounted for 95% of the total root K.

Relationships between K in soil and root extracts

There were four positive, significant relationships found for K, of the 12 relationships considered between adjacent samples of root

Table 18 --Mean K concentration extracted from soils and adjacent corn roots at eight locations

Location number	Sites	Soil extract on 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total
		ppm K				
5	5	381 b*	53.7 b	526 ab	490 b	1,070 b
6	2	313 b	50.0 b	890 ab	1,120 a	2,060 ab
7	4	377 b	72.3 ab	211 b	183 ab	468 b
8	3	408 b	83.7 ab	1,050 a	657 ab	1,790 ab
9	6	860 a	111.0 a	1,120 a	810 ab	2,230 a
11	2	170 b	28.5 b	155 b	300 b	484 b
12	4	431 b	27.5 b	134 b	241 b	558 b
13	2	667 ab	36.5 b	40 b	145 b	222 b
Mean		450	57.9 d	516 d	493 e	1,110

*Entries followed by the same letter (a, b, or c) in each column and (d, e, or f) in the row are not significantly different at $P = 0.05$

and soil. These relationships were of the mole fraction type [ ] and the mole ratio type [5]. There were two significant relationships found between mole fractions for K in the soil extracts and in the root extracts I and IV. These are as follows:

$$X_1 = 0.001351 - 1.5052(X_{11}) + 90.4198(X_{11})^2 \quad [10]$$

and

$$X_1 = 0.001220 - 0.1632(X_{14}) + 11.4092(X_{14})^2 \quad [11]$$

where X_1 is the mole fraction of K in the soil and X_{11} and X_{14} are the mole fractions of K in root extracts I and IV respectively. Regression equations [0] and [ ] accounted for 26.1% and 32.4%, respectively, of the observed variation. There were also two significant relationships between K mole ratios in the soil extracts and in root extracts I and IV. These are as follows:

$$R_1 = 0.001352 - 1.5038(R_{11}) + 90.2301(R_{11})^2 \quad [12]$$

and

$$R_1 = 0.001216 - 0.1593(R_{14}) + 10.9931(R_{14})^2 \quad [13]$$

where R_1 is the mole ratios of K in the soil and R_{11} and R_{14} are the mole ratios of K in root extracts I and IV. Regression equations [12] and [13] accounted for 26.1% and 32.4%, respectively, of the observed variation.

Effect of location on Ca in soil and root extracts

Root Ca.--Data for root Ca in extract I (Table 19) show significantly larger amounts of Ca in samples from location 7 than those from

Table 19.--Mean Ca concentration extracted from soil and adjacent corn roots at eight locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total
		ppm Ca				
5	5	4,150 ab*	189 ab	386 a	1,620 a	2,190 a
6	2	6,150 a	42 b	133 a	141 a	316 a
7	4	4,670 a	292 a	612 a	233 a	1,120 a
8	3	6,380 a	49 b	116 a	125 a	289 a
9	6	5,040 a	97 ab	150 a	159 a	393 a
11	2	1,050 b	87 ab	123 a	133 a	343 a
12	4	5,320	106 ab	292 a	182 a	579 a
13	2	5,380 a	93 ab	254 a	218 a	565 a
Mean		4,768	119 c	258 d	351 d	724

*Entries followed by the same letter (a, b, or c) in each column and (d, e, or f) in the row are significantly different at P = 0.05.

locat ons 6 and 8 No signIficant difference was found between ocat- t ons for Ca in root extracts , I, and IV On a fresh root basis, Ca in extracts I ranged from 16 to 6 2 ppm, those in root extracts III ranged from 25 to 1,620 ppm, and Ca n root extracts V ranged from 289 to 2,190 ppm.

Soi Ca.--Soil-extractable Ca (Tab e 19) was s gnif cantly more at locations 6, 7, 8, 9, and 12, which ranged from 5,320 to 6,380 ppm than from location 11 which contained only 1,050 ppm.

Effect of extraction on removal of root Ca

Root Ca --Root extractions , II and II removed sign ficant y different amounts of Ca (Table 9) Roo. extraction I,I removed the largest amount of Ca, 351 ppm while root extraction I removed on y 119 ppm, and root extract on II removed 258 ppm. Root extraction III accounted for 48.2% of the total Ca removed.

Re at onsh ps between soil and root Ca

None of the four relationsh ps cons dered between soi Ca and root Ca were found to be statistically signif cant. The relat onsh ps considered were between soIl Ca and Ca in root extracts I, I., I, , and IV.

Effect of location on Sr in soil and root extracts

Root Sr.--Data for Sr n root extracts are summarized in Tab e 20. Samp es from locat on 5 conta ned s gn ficant y larger amounts of Sr in root extract I than those from ocat on 8. No sign ficant d ffer- ences were found between ocat ons for Sr in root extracts II, I.I, and IV. In root extracts I , Sr ranged from 0 1 to 2 8 ppm, in root

Table 20. Mean Sr concentration extracted from soils and adjacent corn roots at eight locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total
		ppm Sr				
5	5	27.7 ab*	3.4 a	2.4 a	5.0 a	10.7 a
6	2	39.5 ab	1.9 ab	0.1 a	0.8 a	2.8 a
7	4	24.9 b	2.4 ab	2.8 a	1.0 a	3.7 a
8	3	29.4 ab	0.3 b	0.3 a	1.8 a	2.4 a
9	6	50.6 a	1.5 ab	0.7 a	0.8 a	3.2 a
11	2	4.4 b	1.5 ab	0.6 a	0.9 a	2.9 a
12	4	29.8 ab	1.5 ab	0.4 a	0.8 a	2.7 a
13	2	32.7 ab	1.5 ab	0.1 a	0.9 a	2.4 a
Mean		29.9	1.8 d	0.9 e	1.5 e	3.9

*Entries followed by the same letter (a, b, or c) in each column and (d, e, or f) in the row are not significantly different at P = 0.05.

extracts III, Sr ranged from 0.8 to 5.0 ppm. In root extracts V Sr ranged from 2.4 to 10.7 ppm.

Soil Sr --Soil samples from location 9 contained 50.6 ppm of extractable Sr which was not significantly more because of the variation between sites than the 24.9 and 4.4 ppm of Sr found in samples from locations 7 and 11, respectively.

Effect of extraction on removal of root Sr

Root Sr --Root extraction I removed significantly larger amounts of Sr than root extraction II and III. Root extraction I accounted for 42.9% of the total root Sr removed.

Relationship between soil and root Sr

None of the 12 relationships considered between Sr in soil extracts and Sr in root extracts were found to be significant.

Effect of location on Mg in soil and root extracts

Root Mg.--Data for Mg in the root extracts are summarized in Table 2. Significant differences were not found between locations for root extracts I, II, III, and IV. In root extracts I, Mg values ranged only from 9.3 to 35.5 ppm, those in root extracts II ranged from 64 to 152 ppm. The total Mg in the root indicated by root extracts IV ranged from 128 to 209 ppm.

Soil Mg --Soil samples from locations 8, 9, and 13 contained 902, 809, and 822 ppm of extractable Mg, respectively which was significantly more than the 436 and 205 ppm of Mg in samples from locations 5 and 11, respectively.

Effect of extraction on removal of root Mg

Root Mg.--All three root extractions removed significantly different amounts of Mg. Root extraction II removed the largest amount.

Table 21 --Mean Mg concentration extracted from so s and ad acent corn roots at eight locat ons

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequent al root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total
				ppm Mg		
5	5	436 b*	27.8 a	41.6 a	130 a	199 a
6	2	735 ab	9.3 a	32.9 a	107 a	149 a
7	4	646 ab	35.5 a	42.3 a	64 a	191 a
8	3	902 a	10.6 a	31.2 a	89 a	128 a
9	6	809 a	19.3 a	37.2 a	94 a	154 a
11	2	205 b	17.2 a	20.3 a	108 a	145 a
12	4	609 ab	18.2 a	25.5 a	134 a	178 a
13	2	822 a	21.2 a	36.6 a	152 a	209 a
Mean		646	19.9 f	33.5 e	110 d	169

*Entries followed by the same letter (a, b, or c) n each column and (d, e, or f) in the row are not different significantly at P = 0 05

Relationships between Mg in soil and root extracts

Of the four relationships considered between root- and soil-extractable Mg, none were significant.

Effect of location on Fe in soil and root extracts

Root Fe --Data for Fe in root extracts, summarized in Table 22, show significant differences between locations for Fe in extract I. Samples for location 7 contained an average of 14 ppm of Fe in this extract compared to 0.0 and 0.3 ppm obtained in samples from locations 8 and 9. There was no significant difference between locations for Fe in extracts II, III, and IV. In root extracts III, Fe values ranged from 2.4 to 7.5 ppm, those in extracts III ranged from .98 to 3.2 ppm Fe, and those in extracts IV ranged from 102 to 328 ppm.

Soil Fe --The Fe in the soil extracts was not significantly different between locations. The concentration of Fe ranged from 0.15 to 3.48 ppm.

Effect of extraction on removal of root Fe

All three root extractions removed significantly different amounts of Fe. Extraction I removed the smallest amount of Fe, 4.1 ppm, while extraction II removed an intermediate amount of Fe. Extraction II removed an average of 183 ppm of Fe which accounted for 93.4% of the total Fe removed.

Relationships between Fe in soil and root extracts

Significant relationships were not found between Fe in soil extracts and Fe in the root extracts.

Table 22.--Mean Fe concentration extracted from soils and adjacent corn roots at eight locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	Ash	Total
		mean		ppm Fe		
5	5	0.86 a*	7.1 ab	6.2 a	169 a	183 a
6	2	0.80 a	1.5 ab	2.4 a	98 a	102 a
7	4	0.92 a	14.0 a	17.5 a	190 a	221 a
8	3	0.37 a	0.3 b	2.5 a	102 a	105 a
9	6	0.73 a	1.0 b	6.2 a	104 a	111 a
11	2	0.15 a	2.7 ab	13.0 a	312 a	328 a
12	4	3.48 a	2.3 ab	14.8 a	256 a	273 a
13	2	0.70 a	3.6 ab	7.3 a	233 a	244 a
Mean		1.00	4.1 f	8.7 e	183 d	195.9

*Entries followed by the same letter (a, b, or c) in each column and (d, e, or f) in the row are not different significantly at $P = 0.05$.

Effect of location on Mn in soil and root extracts

Root Mn.--Data for Mn are summarized in Table 23. Significant differences were obtained between locations for Mn in extracts II, III, and IV. There were no significant differences between locations for Mn in root extracts I which ranged from 0.01 to 3.53 ppm. Samples from location 11 contained 4 ppm of Mn, in extract I, which was a larger amount than the 0.4 to 6.5 ppm found in samples from locations 5, 6, 7, 8, 9, 12, and 13. The 13 ppm of root extract III Mn found in samples from location 1 was significantly larger than those from locations 5, 6, 8, and 9 where Mn values ranged from 0.9 to 3 ppm. The combined effect of the higher Mn at location 11 was reflected in the 28 ppm of Mn found in extract IV compared to those from locations 6, 8, and 9 which ranged from 1.8 to 4.2 ppm.

Soil Mn.--The Mn in the soil extracts were not significantly different between locations. The concentration of Mn ranged from 0.15 to 1.08 ppm.

Effect of extraction on removal of root Mn

Root Mn.--Root extractions II and III removed significantly larger amounts of Mn than root extraction I. Extractions II and III accounted for all except 8.3% of the total Mn removed.

Relationships between Mn in soil and root extracts

Significant relationships were not found between Mn in soil extracts and Mn in the root extracts.

Effect of location on Cu in soil and root extracts

Root Cu.--Data for Cu are summarized in Table 24. Significant

Tab e 23 --Mean Mn concentration extracted from so ls and adjacent corn roots at eight locat ons

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total
		ppm Mn				
5	5	0.20 a*	3.53 a	6.5 b	3.1 b	13.1 ab
6	2	0.25 a	0.01 a	0.4 b	1.4 b	1.8 b
7	4	0.18 a	0.98 a	3.3 b	6.4 ab	10.7 ab
8	3	0.53 a	0.20 a	2.5 b	0.9 b	3.6 b
9	6	1.08 a	0.22 a	2.6 b	2.2 b	4.2 b
11	2	0.85 a	1.40 a	14.0 a	12.9 a	28.3 a
12	4	0.18 a	0.10 a	4.2 b	5.8 ab	10.0 ab
13	2	0.15 a	0.20 a	2.6 b	4.5 ab	7.2 ab
Mean		0.43	0.83 e	4.5 d	4.7 d	9.9

*Entries fo lowed by the same letter (a, b, or c) in each co umn and (d, e, or f) n the row are not d fferent sign ficant y at P = 0 05.

Table 24.--Mean Cu concentration extracted from soils and adjacent corn roots at eight locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total
		ppm Cu				
5	5	0.30 a*	90 a	5.1 a	6.1 a	3.1 a
6	2	0.00 c	0.10 a	1.2 a	2.4 a	3.7 ab
7	4	0.15 b	1.95 a	5.9 a	2.4 a	9.6 ab
8	3	0.13 b	0.07 a	1.0 a	1.8 a	2.8 b
9	6	0.17 b	0.22 a	4.8 a	3.3 a	7.1 ab
11	2	0.00 c	0.15 a	1.8 a	4.2 a	6.2 ab
12	4	0.13 b	0.01 a	4.2 a	3.8 a	8.0 ab
13	2	0.15 b	0.01 a	3.4 a	4.8 a	8.2 ab
Mean		0.13	0.55 e	3.4 d	3.6 d	7.3

*Entries followed by the same letter (a, b, or c) in each column and (d, e, or f) in the row are not different significantly at P = 0.05

differences were obtained between locations for Cu in extracts IV. There were no significant differences between locations for Cu in root extracts I, II, and III, which ranged from 0.01 to 1.95 ppm, from 0 to 5.9 ppm, and from 1.8 to 6.1 ppm, respectively. Samples from location 5 contained 13.1 ppm of Cu in extract IV which was a larger amount than those from location 8 which contained 2.8 ppm.

Soil Cu.--Soil Cu was not detectable by the method employed at locations 2 and 11 (Table 24). Detectable soil Cu was highest at location 5.

Effect of extraction on removal of root Cu

Root Cu.--Root extraction I (Table 24) removed significantly smaller amounts of Cu, 0.55, than did extractions II and III which removed 3.4 and 3.6 ppm, respectively. Root extractions II and III removed all except 7.3% of the total root Cu.

Relationship between Cu in soil and root extracts

None of the four relationships considered between soil extract Cu and root extract Cu were found to be significant.

Effect of location on Zn in soil and root extracts

Root Zn.--Data for Zn, summarized in Table 25, showed significant differences between locations for Zn in extracts I and IV. Samples from location 7 contained 7.9 ppm of Zn in root extract I which was significantly more than the 2.5 ppm of Zn in roots from location 8. No significant differences were found between locations for Zn in either extracts II, which ranged from 3.0 to 10.8 ppm, or extracts III, which ranged from 0.8 to 7.5 ppm. The combined root extracts from location 7 also contained a significantly larger amount of Zn than those from location 8.

Table 25. Mean Zn concentration extracted from soils and adjacent corn roots at eight locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	Total
		ppm Zn				
5	5	0.74 a*	5 8 ab	6.5 a	2 2 a	4.4 ab
6	2	--	2.4 ab	3.0 a	0 8 a	6 2 ab
7	4	0 55 a	7 9 a	10.8 a	7.5 a	26. a
8	3	0.33 a	2.5 b	3.5 a	0.7 a	6.6 b
9	6	0.53 a	4.0 ab	6.6 a	2.5 a	14.1 ab
11	2	0.30 a	5.4 ab	3.3 a	1.9 a	10.6 ab
12	4	0.40 a	3.6 ab	5.8 a	1.8 a	11.2 ab
13	2	0.40 a	3.0 ab	3.6 a	0.9 a	7.4 ab
Mean		0.4 b	4.3 d	5.4 d	2.3 e	12.1

*Entries followed by the same letter (a, b, or c) in each column and (d, e, or f) in the row are not different significantly at P = 0 05

Soil Zn.--No significant difference was observed between locations for Zn in soil extracts which ranged from 0.30 to 0.74 ppm.

Effect of extraction on removal of root Zn

Root Zn.--Root extracts I and II (Table 25) removed significantly larger amounts of Zn which were 4.3 and 5.4 ppm, respectively, than root extract on III which removed an average of 2.3 ppm. Root extracts I and II accounted for 80.8% of the total Zn removed.

Relationship between Zn in soil and root extracts

There were three positive significant relationships found between Zn in soil extracts and Zn in root extracts. These are as follows

$$\text{Soil Zn} = 0.1037+0.08512\ (Zn_1) \qquad [14]$$

also

$$\text{Soil Zn} = 0.2677+0.03680\ (Zn_2) \qquad [15]$$

and

$$\text{Soil Zn} = 0.2677+0.01758\ (Zn_4) \qquad [16]$$

where (Zn_1), (Zn_2), and (Zn_4) are the ppm of Zn in root extracts I, II, and IV, respectively. Regression equations [14], [15] and [16] accounted for 38.2, 27.1, and 23.8%, respectively, of the observed variation.

Heliconia Root and Leaf Analysis and Soil Analysis From Six Locations in Eastern Panama

Effect of location on P in root extracts

Data for P in root extracts which are summarized in Table 26 show significant differences between locations for root extracts II, III, and IV. No detectable amount of P was removed by root extracts or

Table 26 --Mean P concentration extracted from soils and adjacent heliconia roots at six locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total
		ppm P				
1	2	0.0	0.0	59 ab*	149 a	208 a
2	2	0.0	0.0	28 ab	88 ab	116 ab
3	9	0.0	0.0	16 b	37 b	52 b
4	2	0.0	0.0	45 ab	82 ab	77 ab
5	4	0.0	0.0	81 a	75 ab	156 a
6	2	0.0	0.0	69 ab	69 ab	137 ab
Mean		0.0	0.0 e	49.7 d	83 d	124

*Entries followed by the same letter (a, b, or c) in each column and (d, e, or f) in the row are not different significantly at P = 0.05

Means are based on 21 observations.

n the so extracts Samples from ocat on 5 contained a sign fi- cantly larger amount of P in root extract I than those from ocation 3. Roots from ocation conta ned sign ficantly arger amounts of P in root extract II than samples from location 3. Total P in roots from ocations and 5 were sign ficantly arger than those from location 3.

Effect of location on K in root and so, extracts and in leaf tissue

Root K --Data, wh ch are summarized n Table 27, show that samples from ocations 5 and 6 contained s gn f cantly arger amounts of K in root extracts I wh ch were 1,390 and 1,580 ppm, respectively, than n roots from locat on 2 which contained 246 ppm. There were no sig- n ficant differences between locat ons for K in root extracts III wh ch ranged from 327 to 6,480 ppm. There were also no s gnificant differ- ences between locations for K n root extracts V which conta ned from 758 to 2,430 ppm.

Soil K --There were no d fferences between ocat ons for K in the soi extracts wh ch ranged from 80 to 225 ppm (Table 27)

Leaf K.--The concentration of K in the eaf tissue (Tab e 27) ranged from 2.72 to 1.84%.

Effect of extraction on removal of root K

Root K.--Data, which are summarized in Table 27, show that root extraction I removed significantly lower quant ties of K, 95 ppm, than root extractions and III Root extractions I and I I removed 902 and 692 ppm, of K, respective y, which accounted for a but 5.62% of the total K in the roots.

Table 27.--Mean K concentration extracted from so s ad acent he icoria roots, and leaf tissue at six locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total	Leaf tissue
		ppm K					%
1	2	154 a*	100 ab	846 ab	1,480 a	2,430 a	--
2	2	80 a	66 b	246 b	327 a	639 a	2.03+
3	9	208 a	53 b	1,030 ab	783 a	1,870 a	2.07
4	2	214 a	51 b	361 ab	511 a	923 a	2.73
5	4	202 a	123 a	1,390 a	566 a	2,080 a	2.03
6	2	225 a	177 a	1,540 a	486 a	2,200 a	1.84
Mean		181	95 e	902 d	692 d	1,690	2.14

*Entr es fol owed by the same letter (a, b, or c) n each column and (d, e, or f) in the row are not different sign ficantly at P = 0.05.

+No statist cal ana ysis were attempted on the leaf tissue because of the small number of observations. Sites, as listed, app y only to so and root extract values.

Relationships between K in soil and root extracts and in leaf tissue

There were no sign ficant re attonships found, of the 2 considered, between K in soil extracts and K in root extracts.

Also no sign ficant re at onsh ps were found, of the three considered, between K in soil extract and K in leaf tissue.

Effect of location on Ca in soil and root extracts and in leaf tissue

Root Ca.--S gnif cant differences between locat ons were found for root Ca in extracts I and II (Table 28). At locations ., 4, and 6, roots conta ned sign ficant y larger amounts of Ca in root extracts I which ranged from 78 to 194 ppm, than those from ocation 3 wh ch contained 72 ppm. Roots from locat on 5 contained a s gn f cantly larger amount of Ca in extract I than those from location 3. There was no sign ficant d fference between locat ons for Ca in either root extracts III wh ch ranged from 865 to ,700 ppm,or n root extracts IV which ranged from 1,290 to 2,440 ppm.

Soil Ca. There was no signi ficant d fference between locat ons for Ca in the so extracts wh ch ranged from 3,970 to 6,440 ppm (Table 28).

Leaf Ca --The concentration of Ca in the leaf tissue (Table 28) ranged from 4,580 to 7,750 ppm between locations.

Effect of extraction on removal of root Ca

Root Ca.--All three root extractions removed signi ficantly dif ferent amounts of Ca (Tab e 28) Root extraction III removed the largest amount of Ca, while root extraction removed the sma est amount, and root extraction I removed an ntermed ate quant ty Root extraction I I accounted for 66 1% of the tota Ca extracted from the roots.

Table 28.--Mean Ca concentration extracted from soils, adjacent hemlock roots, and leaf tissue at six locations

Location number	Sites	Soil extract 0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total	Leaf tissue
		ppm Ca					
1	2	6,440 a*	194 a	548 ab	1,700 a	2,440 a	---
2	2	4,060 a	152 ab	305 ab	865 a	1,320 a	5,480
3	9	5,400 a	72 b	347 b	873 a	1,290 a	4,960
4	2	3,970 a	78 b	418 ab	1,150 a	,650 a	4,580
5	4	4,750 a	104 ab	656 a	878 a	,640 a	5,930
6	2	6,340 a	134 a	575 ab	1,590 a	2,300 a	7,750
Mean		5,160	122	475 f	1,170 e	1,770 d	5,740

*Entries followed by the same letter (a, b, or c) in each column and (d, e, or f) in the row are not different significantly at P = 0.05.

Relat onsh ps between Ca in soil and root extracts and in leaf tissue

No significant relationships were found, of the four cons dered, between Ca in soil extracts and Ca in root extracts.

There was a negative significant relationship between Ca in soil extracts and Ca in leaf t ssue, which is as follows.

So Ca = 34258-49-10 2964(Ca$_5$,+0.0008810(Ca$_5$)^2 [.

where (Ca$_5$) 's the concentration of eaf Ca expressed in ppm The regression equat on [7] accounted for 46.7% of the observed variation Since a negative correlation between soil Ca and leaf Ca is not reported in the l terature an examination of the raw date was made The raw data showed that all samples contributing to this negat ve relationship were from location 3 (Tab e 29) which contained arge quantities of free CaCO$_3$ The fact that Ca n the hel conta leaf t ssue varied l ttle between locat ons and the extractable soi Ca was higher at this location because of the presence of free CaCO$_3$ explains the negative relationship satisfactorily.

Effect of location on Sr in soil and root extracts and in leaf tissue

Root Sr.--Data for Sr are summar zed in Tab e 30 5 gnificant differences existed between ocat ons for Sr in root extracts I. Samples from locations I, 5 and 6 contained significantly larger amounts of Sr ranging from 1 8 to 2.2 ppm, than those from locat on 4 wh.ch contained only 0.5 ppm There was no sign f cant difference between ocations for Sr in root extracts II, III, and IV. Root extracts I, ranged from 2.9 to 4.3 ppm root extracts III from 2.9 to 4 3 ppm, and root extracts IV ranged from 5.3 to 2.9 ppm.

Tab e 29. -Indiv dual samples from Trocha show ng Ca in soil extracts leaf Ca, and so pH

Location	Soil extract	Leaf tissue	Soil pH
	ppm Ca		
3	1,970	6,030	5.1
3	8,090	3,900	7.4
3	6,450	4,450	6.8
3	5,200	4,750	6.6
3	6,970	4,650	6.0
3	5,510	5,380	6.4
3	5,120	5,000	6.1
3	5,260	5,230	5.8
3	4,040	5,230	5.7

Table 30.--Mean Sr concentration extracted from soils, adjacent heliconia roots, and leaf tissue at six locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total	Leaf tissue
		ppm Sr					
1	2	21.4 a*	2.1 a	2.4 a	4.2 a	8.6 a	--
2	2	30.0 a	1.1 ab	2.5 a	2.9 a	6.5 a	22.3
3	9	33.7 a	1.6 ab	2.4 a	3.9 a	7.9 a	28.0
4	2	18.5 a	0.5 b	1.9 a	3.0 a	5.3 a	9.8
5	4	22.7 a	2.2 a	3.7 a	3.3 a	4.2 a	25.1
6	2	22.2 a	1.8 a	1.9 a	4.3 a	7.9 a	1.3
Mean		24.8	1.6 e	2.5 d	3.6 d	7.6	17.9

*Entries followed by same letter (a, b or c) in each column and (d, e, or f) in the row are not different significantly at P = 0.05

Soil Sr.--There were no significant differences between locations for Sr in soil extracts (Table 30) which ranged from 18.5 to 33.7 ppm.

Leaf Sr.--The concentration of Sr in the leaf tissue (Table 30) ranged from 9.8 to 28.0 ppm.

Effect of extraction on removal of root Sr

Root Sr.--Root extraction I and II removed significantly larger amounts of Sr than extraction III. Root extracts II and III removed all but 21.1% of the root extractable Sr.

Relationships between Sr in soil and root extracts and in leaf tissue

There were four positive significant relationships, of the 12 considered, between soil- and root-extractable Sr. Two of these relationships were of the mole fraction type as shown in equation [4]. These are as follows:

$$X_2 = 0.04393-0.1884(X_{21})+2.2153(X_{21})^2 \qquad [18]$$

and

$$X_2 = 0.02880+0.3585(X_{22}) \qquad [19]$$

where (X_2) is the mole fraction of Sr in the soil and (X_{21}) and (X_{22}) are the mole fractions of Sr in root extracts I and II, respectively. Regression equations [18] and [19] accounted for 25.2 and 31.4% of the observed variation, respectively. The other two relationships were for the mole ratios expressed in equation [6]. These are as follows

$$R_2 = 0.04396-0.1859(R_{21})+2.1776(R_{21})^2 \qquad [20]$$

and

$$R_2 = 0.02884+0.3584(R_{22}) \quad [21]$$

where R_2 is the mo e ratio of Sr in the soil and ($R_{2,}$) and ,R_{22}) are the mole rat os of root extracts and il, respectively Regression equat ons [20] and [?] accounted for 25.1 and 31.4% of the observed variation, respectively.

There were two positive significant relationships, of the three considered between Sr in soil extracts and Sr in leaf tissue One relationship was of the mo e fract on type given n equation [4] and is as follows'

$$X_2 = 0.01935+1.4186(X_{25})-16.869(X_{25})^2 \quad [22]$$

where X_2 is the mo e fraction of Sr in the soil and (X_{25}) is the mole fraction of Sr in leaf tissue. The second relat onsh p was of the mole rat o type indicated in equation [6] and s as follows

$$R_2 = 0.01937+1.4190(R_{25})-16.8538(R_{25})^2 \quad [23]$$

where (R_2) is the mo e ratio of Sr in the soil and (R_{25}) is the mole ratio of Sr in the eaf tissue Regression equations [?2] and [23] each accounted for 36.7% of the observed variation

Effect of locat.on on Mg in root and so.l extracts and in leaf Mg

Root Mg.--The root data (Tab e 3) show that roots from ocat ons 2, 4, and 5 contained significantly larger amounts of Mg in root extracts 1 rang ng from 32 to 59 ppm, than at location 3 wh ch contained 27 ppm. There was no sign ficant d fference between locations for Mg

Table 31.--Mean Mg concentration extracted from soils, adjacent heliconia roots, and leaf tissue at six locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction: 1.0 N NH_4Cl	Sequential root extraction: 1.0 N HCl	Sequential root extraction: Ash	Sequential root extraction: Total	Leaf tissue
		ppm Mg					
1	2	460 b*	41 ab	193 a	748 a	981 a	--
2	2	963 ab	49 a	98 a	648 a	794 a	3,750
3	9	814 b	27 b	159 a	467 a	653 a	3,700
4	2	1,420 a	59 a	120 a	471 a	650 a	4,750
5	4	724 b	32 a	155 a	330 a	516 a	3,520
6	2	669 b	34 ab	172 a	249 a	454 a	3,780
Mean		842	40 f	150 e	486 d	676	3,900

*Entries followed by the same letter (a, b, or c) in each column and (d, e, or f) in the row are not different significantly at P = 0.05

in root extracts I , III, and V The Mg ranged from 98 to 93 ppm for extract I, from 249 to 748 ppm for extract III and from 454 to 981 ppm for extract IV.

So Mg.--Soi samples from locat on 4 contained sign ficantly larger quant ties of Mg in soil extracts ,420 ppm, than those from ocations , 3, 5, and 6 which contained from 669 to 8 4 ppm (Tab e 30)

Leaf Mg --The concentration of Mg in eaf tissue (Table 31) ranged from 3,520 to 4,750 ppm.

Effect of extraction on remova of root Mg

A l three root extractions (Table 3) removed s gn ficant y different quant ties of Mg Root extraction I removed the sma l est amount of Mg, 40 ppm, while root extraction II removed intermed ate quant ties. Root extract on II removed the argest amounts of Mg which averaged 486 ppm and this was 7 .9% of the Mg extracted from the root.

Re at onsh ps between Mg in soil and root extracts and in leaf tissue

There were no s gn ficant relat onsh ps, of the four cons dered, between the Mg in the root extracts and the soil extract.

There was a positive sign ficant re at onsh p between Mg in the so extracts and Mg in leaf tissue. This re at onsh p is as fo ows

$$\text{Soil Mg} = 293.64+0.1524(Mg_5) \qquad [24]$$

where (Mg_5) s the concentration of leaf Mg expressed n ppm Regression equation [24] accounted for 24.0% of the observed variation

Effect of location on Fe in soil and root extracts and in leaf tissue

Root Fe. -Data for root Fe are summarized in Table 32 and indicate that samples from location 2 contained significantly larger amounts of Fe in root extracts than those from locations 1, 3, 5, and 6 which ranged in Fe values from 0.5 to 4.2 ppm. Samples from location contained 50.8 ppm of Fe in root extracts I, which was significantly more than those from locations 5 and 6 which contained 2.9 and 2.6 ppm of extractable Fe, respectively. Significance differences were not found between locations for Fe in root extracts I although these values ranged from 103 to 220 ppm. Samples from location 2 contained significantly larger amounts of Fe in root extract IV than in samples from locations 5 and 6 which contained approximately one-half those from the former location.

Soil Fe.--Significant differences were not found between locations for Fe in soil extract (Table 32) which ranged from 0.3 to 2.2 ppm.

Leaf Fe --The concentration of Fe in the leaf tissue (Table 32) ranged from 47 to 24 ppm.

Effect of extraction on removal of root Fe

All three root extractions (Table 32) removed significantly different concentrations of Fe. Only 6.3 ppm of Fe were removed by root extract II compared to 19. ppm by root extract I and 154 ppm of Fe removed by root extract III. The latter accounted for 86.0% of the total Fe extracted.

Relationships between Fe in soil and root extracts and in leaf tissue

There were two positive significant relationships, of the four considered, between Fe in root extracts and corresponding soil extracts

Table 32.--Mean Fe concentration extracted from soils, adjacent hemlock roots, and leaf tissue at six locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	Total	Leaf tissue
		ppm Fe					
1	2	1.6 a*	1.6 b	50.8 a	176 a	228 ab	--
2	2	2.2 a	18.0 a	19.1 ab	220 a	257 a	91
3	9	1.5 a	4.2 b	15.3 ab	125 a	144 ab	241
4	2	1.8 a	11.3 ab	23.6 ab	194 a	229 ab	161
5	4	0.5 a	2.2 b	2.9 b	103 a	108 b	190
6	2	0.3 a	0.5 b	2.6 b	106 a	109 b	37
Mean		1.3	6.3 f	19.1 e	154 d	179	720

*Entries followed by the same letter (a, b, or c) in each column and (d, e, or f) in the row are not different significantly at P = 0.05.

The first relationship is as follows:

$$\text{Soil Fe} = 0.3799+0.3529(\text{Fe}_1)-0.01361(\text{Fe}_1)^2 \quad [25]$$

where (Fe_1) is the concentration of Fe in root extract I expressed in ppm. The second relationship is

$$\text{Soil Fe} = 0.4152+0.09894(\text{Fe}_2)-0.001001(\text{Fe}_2)^2 \quad [26]$$

where (Fe_2) is the concentration of Fe in root extract II expressed in ppm. Regression equations [25] and [26] accounted for 4 ,5 and 41.4% of the observed variation.

No significant relationship was found between Fe in soil extracts and Fe in leaf tissue.

Effect of location on Mn in root and soil extracts and in leaf tissue

Root Mn.--No significant differences were found between locations for Mn found in root extracts I, II, III, and IV. The concentration of Mn in root extracts I ranged from 0.20 to 0.85 ppm, from 1.8 to 5.6 ppm in root extracts II, from 1.8 to 10.2 ppm extracts III, and from 5.4 to 15.6 ppm for extracts IV (Table 33).

Soil Mn. Samples from location 2 (Table 33) contained significantly larger amounts of Mn in the soil extracts than those from the other locations. These values were 2.30 ppm for the former location and ranged from 0.25 to 0.86 ppm in the latter soils.

Leaf Mn.--The concentration of Mn in the leaf tissue ranged from 96 to 277 ppm.

Tab e 33 ·Mean Mn concentrat on extracted from so s, ad acent hel conia roots, and leaf tissue at six locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total	Leaf tissue
				ppm Mn			
1	2	0 25 b*	0 20 a	' 8 a	5 3 a	7.3 a	--
2	2	2.30 a	0.85 a	3.7 a	5.6 a	10.1 a	125
3	9	0.86 b	0.43 a	5.0 a	10.2 a	15.6 a	227
4	2	0.65 b	0.70 a	5.6 a	3.8 a	0.1 a	98
5	4	0.60 b	0.68 a	3.4 a	3.5 a	7.6 a	277
6	2	0.25 b	0.35 a	3.3 a	1.8 a	5.4 a	96
Mean		0.49	0.54 e	3.8 d	5.0 d	9.4	165

*Entr es fo owed by the same letter (a, b, or c) n each co umn or (d, e, or f) in the row are not different signif cantly at P = 0.05.

Effect of extraction on removal of root Mn

Data summarized in Table 33 show that root extracts I and II contained significantly larger amounts of Mn than root extract I. The 3.8 and 5.0 ppm of Mn removed by root extracts II and III accounted for all but 5.7% of the total root Mn.

Relationships between Mn in soil and extracts and in leaf tissue

There were two positive, significant relationships for Mn, of the four considered. The first relationship is as follows:

$$\text{Soil Mn} = 0.1239+1.3331(Mn_1) \qquad [27]$$

where (Mn_1) is the concentration of Mn in root extract I expressed in ppm. The second relationship is as follows:

$$\text{Soil Mn} = 0.4905+0.207\ (Mn_4) - 0.005755(Mn_4)^2 \qquad [28]$$

where (Mn_4) is the concentration of Mn in root extract IV expressed in ppm. Regression equations [27] and [28] accounted for 29.6 and 32.5% of the observed variation.

No significant relationships were found between Mn in soil extracts and Mn in leaf tissue.

Effect of location on Cu in soil and root extracts and in leaf tissue

Root Cu --Data for Cu are summarized in Table 34. There was a significant difference between locations for Cu in root extracts I and II. Locations 2, 5, and 6 contained significantly larger amounts of Cu in root extracts, which ranged from 0.5 to 2.4 ppm, than samples from

Table 34 --Mean Cu concentration extracted from soils adjacent heliconia roots, and leaf tissue at six locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total	Leaf tissue
		ppm Cu					
1	2	0.20 a*	0.1 b	3.9 ab	8.1 a	12.0 a	--
2	2	0.35 a	2.4 a	8.1 ab	7.8 a	18.2 a	19.1
3	9	0.79 a	1.1 b	4.7 b	6.7 a	12.6 a	23.7
4	2	0.35 a	1.8 ab	6.6 ab	4.0 a	2.4 a	26.0
5	4	0.20 a	0.7 a	5.8 ab	8.4 a	14.8 a	22.0
6	2	0.20 a	0.5 a	9.7 a	6.4 a	16.6 a	13.8
Mean		0.35	1.1 e	6.5 d	6.9 d	14.5	20.9

*Entries followed by the same letter (a, b or c) in each column and (d e) in the row are not different significantly at P = 0.05

locations 1 and 3 which contained 0.1 and 1. ppm, respectively. Samples from location 6 contained 9.7 ppm of Cu in root extracts I which was significantly more than in samples from location 3 which contained 4.7 ppm. Significant differences were not found between locations for Cu in root extracts III and IV. Root extracts II ranged in Cu content from 4.0 to 8.4 ppm and root extracts IV ranged from 12.0 to 18.2 ppm of Cu.

Soil Cu --There was no significant difference among locations for Cu in the soil extracts which ranged from 0.20 to 0.79 ppm (Table 34).

Leaf Cu --The concentration of Cu in leaf tissue (Table 34) ranged from 13.8 to 26.0 ppm.

Effect of extraction on removal of root Cu

Root extract I removed significantly less Cu than extracts II and III (Table 34). Root extraction I removed .1 ppm of Cu while root extracts II and III removed 6.5 and 6.9 ppm of Cu, respectively. Root extractions II and III accounted for 92.4% of the total root Cu.

Relationships between Cu in soil and root extracts and leaf tissue

Significant relationships were not found, of the four considered between Cu in soil extracts and Cu in leaf extracts I. Also no significant relationship was found between soil-extract Cu and leaf-tissue Cu.

Effect of location on Zn in soil and root extracts and in leaf tissue

Root Zn. The data for Zn analysis are summarized in Table 35. Root samples from location 2 contained 26 ppm of Zn in root extracts which was significantly more than those at all other locations. Zn in these extracts ranged from 8 to 4.3 ppm. No significant differences

Table 35 --Mean Zn concentration extracted from soils adjacent to rice roots, and leaf tissue at six locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total	Leaf tissue
		ppm Zn					
1	2	0.75 ab*	3.4 b	6.4 a	4.5 a	14.2 b	--
2	2	5.95 a	26.1 a	7.6 a	2.3 a	36.0 a	27.9
3	9	1.94 ab	4.3 b	6.8 a	3.3 a	14.4 b	42.3
4	2	5.45 ab	2.7 b	8.0 a	2.3 a	13.0 b	30.3
5	4	0.75 b	3.9 b	11.7 a	3.2 a	18.8 b	38.6
6	2	0.60 b	1.8 b	8.6 a	2.3 a	12.7 b	43.0
Mean		2.57	7.0 de	8.2 d	3.0 e	18.2	30.4

*Entries followed by the same letter (a, b, or c) in each column and (d, e, or f) in the row are not different at P = 0.05.

were found between ocations for Zn n root extracts II and I I In root extracts II, Zn ranged from 6 4 to 11,7 ppm and n root extract III, Zn ranged from 2 3 to 4.5 ppm Samples from locat on 2 conta ned sign ficantly larger amounts of Zn n the so l ex racts than locations 5 and 6. The former averaged 5.95 ppm compared to 0 75 and 0 60 ppm, respectively in the latter samples (Table 35).

Leaf Zn --The concentration of Zn in the leaf tissue (Table 35) ranged from 27.9 to 43.0 ppm.

Effect of extraction on removal of root Zn

Root Zn --Root extracts II and III removed sign ficantly different quantities of Zn. Root extraction III removed an average of 3 0 ppm of Zn whereas root extracts II removed 8,2 ppm of Zn Root extraction II accounted for 45.1% of the total root Zn.

Relationships between Zn in soil and root extracts and in leaf tissue

Sign f cant relationships were not found, of the four considered between Zn n soil extracts and Zn n root extracts I Also no significant relationsh p was found between soi extract Zn and leaf tissue Zn.

Paraquagrass Root and Leaf Analysis and Soil Analys s from Six Locations in Eastern Panama

Effect of location on P in root extracts

Root P.--Data for root P are summarized n Table 36. Significant differences were not found between locations for root extracts II, I I, and V. There was no detectable P in root extract . Root extracts II contained from 14 3 to 20.6 ppm of P compared to a range in P from 49.3 to 50. in root extracts I, . Total P in the roots ranged only from 64.4 to 69.6 ppm between locations.

Table 36.--Mean P concentration extracted from soils, and adjacent jaraguagrass roots, at three locations+

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total
		ppm P				
1	27	0.0	0.0	20.6 a*	49.0 a	69.9 a
4	26	0.0	0.0	14.3 a	50.1 a	64.4 a
16	26	0.0	0.0	6.7 a	49.3 a	66.0 a
Mean		0.0	0.0	17.2 e	49.5 d	66.7

*Entries followed by the same letter (a, b, or c) in each column and (d, e) in the row are not different significantly at P = 0.05

+Samples were taken from the jaraguagrass portion of fertilizer trials conducted by M. W. Silvey (5). Treatments included top-dressing with (1) 90 kg/h of K derived from sulfate of potash and (2) 100 kg/h of P derived from triple superphosphate, 90 kg/h of K derived from sulfate of potash, and 90 kg/h of N derived from urea. This latter treatment was randomly split with three levels of Zn applied as a spray at 0, 15, and 30 kg/h of Zn derived from zinc sulfate. Subsequent tables dealing with jaraguagrass were from these trials.

Effect of extraction on removal of root P

Root P.--All three root extractions removed significantly different amounts of P (Table 36). No detectable P was removed with root extract I while extracts I and II removed 17.2 and 49.5 ppm P, respectively. Root extraction III accounted for 74.3% of the total P extracted.

Effect of locations on K in root and soil extracts and in leaf tissue

Root K.--The data in Table 37 show that there were significant differences between locations for K in root extracts I, II, and III. Samples from locations 4 and 16 contained significantly larger amounts of K in root extracts I, than those from location 1 which contained 17.5 ppm. Similarly roots from locations 4 and 16 contained significantly larger amounts of K which were 292 and 240 ppm respectively, than those from location 1 which contained 49 ppm. No significant difference was found between locations for K in root extracts III which ranged from 41 to 457 ppm. Samples from locations 4 and 16 contained significantly larger amounts of total root K, as shown by the 702 and 780 ppm, found in extracts IV as compared to those from location 1 having 578 ppm of K.

Soil K.--Soils sampled from location 4 contained 672 ppm of K which was significantly larger than the amounts of K in the soil extracts from locations 1 and 16 which contained 316 and 285 ppm, respectively (Table 37).

Leaf K.--The concentration of K in leaf tissue (Table 37) ranged from 1.90 to 1.73% of the total dry weight.

Effect of extraction on removal of root K

Root K.--Removal of K from the roots in extracts averaged 25.3

Table 37 --Mean K concentration extracted from soils adjacent to aragua grass roots, at three locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total	Leaf tissue
		ppm K					%
1	26	285 b*	17.5 b	149 b	411 a	578 b	1.90
4	25	672 a	31.0 a	292 a	457 a	780 a	1.70
16	26	316 a	27.5 a	240 a	434 a	702 a	1.73
Mean		424	25.3 e	227 d	434 d	686	1.78

*Entries followed by the same letter (a, b, or c) in each column and (d, e, or f) in the row are not different significantly at P = 0.05

ppm which was much less than that found in extracts II and III which removed 226 and 426 ppm of K, respectively.

Relationships between K in soil and root extracts and in leaf tissue

There were five positive, significant relationships found, of the 12 considered, between K in soil extracts and K in root extracts. Four of these equations were of the type involving mole fractions [3] and mole ratios [5]. There were two significant relationships found between mole fractions in the soil extracts and root extracts I and III. These equations are as follows:

$$X_I = 0.0006630+0.9945(X_{II}) \quad [29]$$

and

$$X_I = 0.00038370+0.1363(X_{III}) \quad [30]$$

where (X_I) is the mole fraction of K in the soil and (X_{II}) and (X_{III}) are the mole fractions of K in root extracts I and III, respectively. Two of the significant relationships were between mole ratios for K in the soil extracts and root extracts I and II. These equations are as follows:

$$R_I = 0.0006638+0.9959(R_{II}) \quad [31]$$

and

$$R = 0.0003850+0.1358(R_{III}) \quad [32]$$

where R is the mole ratio of K in the soil and (R_{II}) and (R_{III}) are the mole ratios of K in root extracts I and III, respectively. The fifth

significant re ationsh p was between K n the so extracts and K in root extract I. This equation was as follows

$$\text{Soil K} = 29.16+5.869\ (K_I) \qquad [33]$$

where (K_I) 's the concentration of K n root extracts I expressed in ppm Regression equations [29], [30], [ ], [2], and [ ] accounted for 8.4, 8.9, 8.4, 8.9, and 11.2% of the observed var ation, respectively.

No s gn ficant re ationsh ps were found between K n the so extracts and K in the leaf

Effect of locations on Ca in root and soil extracts and in leaf tissue

Root Ca --The Ca extracted from roots (Table 38) showed no s g nificant differences between locat ons for Ca in root extracts I, these values ranged from 146 to 156 ppm Roots from location 6 contained 70 ppm of Ca n root extracts II wh ch s a sign f cant y larger amount than those at ocations 1 and 4 wh ch contained 100 and 38 ppm, respective y. Root samples from locations and 16 conta ned signif - cantly larger amounts of Ca in root extracts II than samples from ocation 4 Samples from ocat on 16 contained s gn ficantly larger amounts of Ca, 45 ppm in root extract IV, than the 362 and 369 ppm of Ca in samples from locations 1 and 4, respectively.

Soil Ca.--There were no significant differences between locations for Ca in the soi extracts which ranged from 2,900 to 4 800 ppm (Table 38).

Leaf Ca.--The concentration of Ca in the leaf t ssue (Table 38) ranged from 4,000 to 4,880 ppm.

Table 38 Mean Ca concentration extracted from soil and adjacent Jaraguagrass roots, and leaf tissue at three locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total	Leaf tissue
		ppm Ca					
1	26	4,810 a*	148 a	100 b	114 a	362 b	4,880
4	26	4,040 a	146 a	138 ab	85 b	369 b	4,000
16	26	2,900 a	156 a	70 a	125 a	451 a	4,680
Mean		3,917	50 d	136 e	108 f	394	4,520

*Entries followed by the same letter (a, b, or c) in each column and (d, e, or f) in the row are not different significantly at P = 0.05.

Effect of extraction on removal of root Ca

Root Ca.--All three root extractions removed s gnif.cantly different amounts of Ca (Table 38). The largest amount of Ca, 150 ppm was removed in root extract on I which accounted for 38 l% of the total Ca removed Root extraction II removed an average of 108 ppm of Ca which was the smal est amount of Ca removed by any extract

Relat onships between Ca in soil and root extracts and in leaf tissue

There were no s gnif cant re ationships, of the four cons dered between Ca in soil extracts and Ca in root extracts.

S gnificant relationships were not found between Ca n the soil extracts and Ca in leaf tissue.

Effect of location on Sr in root and soi. extracts and in leaf tissue

Root Sr.--The data for Sr n roots (Table 39) show that samples from ocat on 16 contained s gn ficantly more Sr in root extracts I than those from ocation . The difference in Sr between these two ocations was 0.78 ppm There was no signif cant differences between locations for Sr in root extracts II wh ch ranged from 0 69 to 0.88 ppm. Roots from location 6 contained s gnif cant y more total Sr than those from location I, the difference averaged 0 68 ppm

Soi. Sr.--Data summarized n Tab e 39 show that soi samp es from locations I and 4 contained significantly large amounts of extracted Sr, 27 9 and 30 7 ppm, than those from ocation 16 wh ch contained 18 6 ppm.

Leaf Sr --The concentrat on of Sr n the eaf tissue (Tab e 39) ranged from 30.9 to 37.5 ppm.

Table 39. Mean Sr concentration extracted from soils, adjacent Jaraguagrass roots, and leaf tissue at three locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total	Leaf tissue
		ppm Sr					
1	26	27.9 a*	0.99 b	0.36 a	0.81 a	2.16 b	37.5
4	26	30.7 a	1.46 ab	0.27 a	0.69 a	2.42 ab	34.5
16	26	18.6 b	1.77 a	0.19 a	0.88 a	2.84 a	30.9
Mean		25.7	1.41 d	0.27 f	0.79 e	2.47	34.3

*Entries followed by the same letter (a, b, or c) in each column and (d, e or f) in the row are not different significantly at P = 0.05

Effect of extraction on removal of root Sr

Root Sr.--A l three root extracts removed significantly different amounts of Sr (Table 39). Root extracts removed 57 l% of the tota Sr extracted. Root extracts I removed the sma est amount of Sr, which averaged only 0.27 ppm

Re at onsh ps between Sr in soil and root extracts and in leaf tissue

One negative, significant relationship, of the 12 considered, existed between Sr in soil extracts and Sr in root extracts (I). This relationship was as follows:

$$\text{Soil Sr} = 28.7616-3.0832(Sr_3) \qquad [34]$$

where (Sr_3) s the Sr content of root extract II expressed in ppm. Regression equation [34] accounted for only 5.5% of the observed variation.

There was no significant re ationship found between Sr in soil extracts and Sr in the leaf tissue

Effect of location on Mg in root and soil extracts and in leaf tissue

Root Mg.--Examination of the Mg data for the root extract ons (Table 40) showed that there was no significant difference n the amount of Mg in root extracts I wh ch ranged from 29 6 to 32.2 ppm. Samples from locat on contained s gnificantly larger amounts of Mg in root extracts II wh ch averaged 31 ppm, than those from locations 4 and 16 hav ng an average Mg content of 23.I and 25 0 ppm, respectively. Roots from location I contained a signif.cantly larger amount of Mg in root extracts I,I, averag'ng 225 ppm, than those from locations 4 and 16 which analyzed 146 and 152 ppm, respectively.

Table 40.--Mean Mg concentrat on extracted from soils, ad acent araqua- grass roots, and leaf tissue at three locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequent.a) root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HC	(III) Ash	(IV) Total	Leaf tissue
1	26	976 b*	29.6 a	31.0 a	225 a	285 a	1,590
4	26	1,377 a	32.2 a	23.1 b	91 b	146 b	2,120
16	26	519 c	31.1 a	25.0 b	96 b	152 b	1,480
Mean		957	31.0 c	26.4 f	137 d	194	1,730

*Entr es followed by the same letter a b, or c) n each column and (d, e, or f) in the row are not d fferent signi f cantly at P = 0 05

Soil Mg.--All three locations were significantly different for Mg in the soil extract (Table 40). Samples from location 4 contained the largest amount of Mg in the soil extracts while samples from location 16 contained the smallest amount.

Leaf Mg. The concentration of Mg in the leaf tissue (Table 40) ranged from 1,480 to 2,120 ppm

Effect of extractions on removal of root Mg

Root Mg.--All three root extracts removed significantly different amounts of Mg (Table 40) Average Mg removed by extracts I,I was 137 ppm, which accounted for 70.6% of the total Mg removed Root extracts I contained the smallest amount of Mg, only 26.4 ppm

Relationships between Mg in soil and root extracts and in leaf tissue

There were no significant relationships, of the four considered, between Mg in soil extracts and Mg in the root extracts.

A positive, significant relationship between Mg in soil extracts and Mg in leaf tissue was found. This relationship was as follows

$$\text{Soil Mg} = 389.03+0.7751(Mg_5) \qquad [35]$$

where (Mg_5) is the concentration of Mg in the leaf tissue expressed in ppm. Regression equation [35] accounted for 48.% of the observed variation

Effect of location on Fe in root and soil extracts and in leaf tissue

Root Fe --The data for Fe are reported in Table 4 . Roots from locations 1 and 4 contained significantly larger amounts of Fe in root extracts I, than those samples from location 16. Similarly these

Table 4 --Mean Fe concentration extracted from soils adjacent araguá grass roots, and leaf tissue at three locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total	Leaf tissue
1	26	0.70 a*	4.10 a	80.0 a	378 ab	462 ab	91.1
4	26	1.13 a	1.83 a	63.6 a	279 b	344 b	108.0
16	26	0.77 a	0.30 b	51.6 b	462 a	514 a	137.0
Mean		0.87	2.07 f	65.1 e	373 d	440	112

*Entries followed by the same letter (a, b, or c) in each column and (d, e, or f) in the row are not different significantly at P = 0.05

samp es from ocat ons 1 and 4 contained s gn f cant y larger amounts of Fe in root extracts , than those from ocation 6 However, roots from ocat ons and 16 conta ned sign ficantly arger amounts of Fe n root extracts I than those from locat on 4 The tota Fe n roots from ocat on 6 was s gn ficantly more than that in samples from either .ocations 1 or 4.

Soil Fe.--There was no significant difference among ocations for soi extract Fe (Table 40) wh ch ranged from 0.70 to 1 13 ppm.

Leaf Fe.--The concentration of Fe in the leaf t ssue Table 41) ranged from 91 to 08 ppm.

Effect of extraction on removal of root Fe

Root Fe.--All three root extracts removed significantly different amounts of Fe (Table 41). Root extracts I removed the largest amount of Fe, 373 ppm, which accounted for 84.8% of the total Fe extracted from the root. Root extract on I removed the smallest amount of Fe which averaged only 2.07 ppm.

Relationships between Fe in soil and root extracts and in leaf tissue

S gn f cant relationships were not found, of the four re ation ships considered, between Fe n the so l extract and Fe in the root extracts

Also no sign ficant re ationship was found between soil-extrac. Fe and leaf-tissue Fe.

Effect of location on Mn in root and soil extracts and in leaf tissue

Root Mn.--Data for Mn summar zed n Tab e 42, were ana yzed statistically and no difference was found among locat ons for Mn n root extracts I, wh ch ranged from 0 21 to 0.54 ppm Roots taken

Table 42.--Mean Mn concentration extracted from soils, adjacent paraguagrass roots, and leaf tissue at three locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total	Leaf tissue
		ppm Mn					
1	26	0.30 b*	0.21 a	8.9 a	8.1 a	17.2 a	28.8
4	26	1.56 a	0.23 a	3.2 b	2.5 b	5.9 b	28.2
16	26	0.18 b	0.54 a	8.9 a	8.2 a	17.6 a	22.6
Mean		0.68	0.33 e	7.0 d	6.3 d	13.6	26.5

*Entries followed by the same letter (a, b, or c) in each column and (d, e, or f) in the row are not different significantly at P = 0.05

from locat ons and 16 cor ared s gn.f cant y larger amounts of Mn n root extracts I than those from oca.ion 4 the d fference betwéen locat ons was 6.0 ppm. Roots from locat ons and 16 a so conta ned larger amounts of Mn in root extracts III han those of ocation 4, the difference was 2.0 ppm Roots From locat ons I and 6 also con ta ned s gn.f cantly arger amounts of Mn n root extracts IV chan at location 4, the difference was nearly 12 ppm.

So I Mn --Soi samples (Table 42) from ocation 4 contained signif cantly larger amounts of extractable Mn which analyzed only 0. 8 and 0.30 ppm, respectively.

Leaf Mn --The concentration of Mn .n eaf t ssue (Tab e 42) ranged from 22.6 to 28.8 ppm.

Effect of extraction on removal of root Mn

Root Mn.--Root extracts 1, and . I removed sign ficant y larger amounts of Mn, which were 7.0 and 6.3 ppm, respective y, than root extracts I which averaged only 0 33 ppm. Root extracts II and III accounted for 97.6% of the total Mn removed.

Re.at ionships between Mn in so.l and root extracts and in leaf tissue

There were three negative sign ficant relationships, of the four considered, between Mn in soil and ad,acent ,araguagrass roots These were as follows

$$\text{Soil Mn} = 1.3864-0.0947(Mn_2) \qquad [36]$$

$$\text{Soil Mn} = 1.2161-0.08264(Mn_3) \qquad [37]$$

and

$$\text{Soil Mn} = 1.4077 - 0.05195(Mn_4) \quad [38]$$

where (Mn_2), (Mn_3), and (Mn_4) were the ppm of Mn in root extracts II, III, and IV, respectively. Regression equations [36], [37], and [38] accounted for 9.6, 8.0, and 10.2%, respectively, of the observed variation.

There was a positive, significant relationship between Mn in soil extracts and Mn in leaf tissue. This relationship was as follows:

$$\text{Soil Mn} = 0.01650 + 0.02472(Mn_5) \quad [39]$$

where (Mn_5) is the concentration of Mn in leaf tissue expressed in ppm. Regression equation [39] accounted for only 5.8% of the observed variation.

Effect of location on Cu in root and soil extracts and in leaf tissue

Root Cu.--The data for Cu in paraguagrass roots (Table 43) showed no significant difference among locations for Cu in root extracts which ranged from 0.21 to 0.52 ppm. All three locations contained significantly different amounts of Cu in root extracts I, II, and IV. Roots from location 16 contained the largest amount of Cu in extracts II while those from location 4 contained only 0.49 ppm. Roots from location 16 also contained the largest amount of Cu in extracts I and IV, which were 3.90 and 9.50 ppm, respectively, those at location 1 contained the smallest amount which averaged 0.28 and 2.0 ppm respectively, for these extracts.

Soil Cu.--All three locations contained significantly different amounts of Cu in the soil extracts (Table 43). Samples from location

Table 43.--Mean Cu concentration extracted from soils, adjacent jaraguagrass roots, and leaf tissue at three locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total	Leaf tissue
		--ppm Cu--					
1	26	0.05 b*	0.30 a	1.40 b	0.28 c	2.0 c	20.2
4	26	0.10 a	0.21 a	0.49 c	2.73 b	3.4 b	17.7
16	26	0.01 c	0.52 a	5.10 a	3.90 a	9.5 a	15.6
Mean		0.05	0.34 c	2.33 d	2.30 d	5.0	17.8

*Entries followed by the same letter (a, b, or c) in each column and (d, e, or f) in the row are not different significantly at P = 0.05

4 contained the largest amount of Cu w th 0 0 ppm, while ocat on 16 contained the sma lest amount wh ch was on y 0 01 ppm

Leaf Cu --The concentration of Cu in the leaf t'ssue (Table 43) ranged from 15.6 to 20.2 ppm.

Effect of extraction on removal of root Cu

Root Cu --Cu content of root extracts I, was significantly different from root extracts and III Root extracts II removed the largest amount of Cu, which averaged 2 33 ppm, wh le root extracts removed the sma l est amount, only 0.34 ppm (Tab e 43, Root extracts II and III accounted for 93.2% of the total Cu removed

Relat onships between Cu in soil and root extracts and in leaf t'ssue

There were three positive, s gn ficant relationships, of the four cons dered, between Cu n so l extract and Cu n root extracts. These relationships are as fol ows:

$$\text{Soil Cu} = 0.03889+0.04898(Cu_1) \qquad [40]$$

$$\text{Soil Cu} = 0.05686-0.02263(Cu_2)+0.01020(Cu_2) \qquad [4]$$

and

$$\text{Soil Cu} = 0.1202-0.03285(Cu_4)+0.003256(Cu_4)^2 \qquad [4]$$

where (Cu), (Cu_2) and (Cu_4) are the root extracts I, I, and IV, respectively expressed n ppm. Regress on equat ons [40] [4], and [47] accounted for 23.4, 44.3, and 43.2%, respect vely, of the observed variation.

No s gnif cant relat.onsh.p was found between Cu n so l extracts and Cu in ,eaf tissue.

Effect of location on Zn in root and soil extracts and in leaf tissue

Root Zn --Data summarized in Table 44 show that roots from location 16 contained significantly larger concentrations of Zn in root extracts than those from location I and 4. Roots from locations 4 and 16 contained significantly larger amounts of Zn in root extracts II than those from location I the difference averaged 5.6 ppm There was no significant differences among locations for Zn in root extracts and IV. The Zn concentration ranged from 2. to 8 9 ppm in extracts III and from 16.8 to 25.1 ppm in extracts IV

Soil Zn.--There was no significant difference between locations for Zn in the soil extracts (Table 44) which ranged from I 60 to .37 ppm.

Leaf Zn.--The concentration of Zn in the leaf tissue (Table 44) ranged from 67.7 to 42 6 ppm.

Effect of extraction on removal of root Zn

No significant difference was found in the amount of Zn removed by root extractions I, II, and II . The amount of Zn extracted ranged from 5.0 to 10.1 ppm (Table 44).

Relationships between Zn in soil and root extracts and leaf tissue

Significant relationships were not found, of the four considered, between Zn in soil extracts and Zn in root extracts

A positive, significant relationship was found between Zn in the soil extracts and Zn in leaf tissue. This relationship is as follows

$$\text{Soil Zn} = 0.4790+0.004489(Zn_5) \qquad [43]$$

Table 44 -Mean Zn concentration extracted from soils, adjacent araguagrass roots, and leaf tissue at three locations

Location number	Sites	Soil extract 1.0 N NH_4Cl	Sequential root extraction (I) 1.0 N NH_4Cl	(II) 1.0 N HCl	(III) Ash	(IV) Total	Leaf tissue
		ppm Zn					
1	26	1.54 a*	4.5 b	6.8 b	8.9 a	20.2 a	42.6
4	26	1.60 a	5.5 b	11.1 a	2.1 a	18.7 a	67.6
16	26	1.37 a	8.7 a	12.3 a	4.0 a	25.1 a	67.7
Mean		1.50	6.2 d	10.1 d	5.0 d	21.3	50.0

*Entries followed by the same letter (a, b or c) in each column and (d, e, or f) in the row are not different significantly at $P = 0.05$

where (Zn_5) is the concentration, in ppm, of Zn in leaf tissue. Regression equation [43] accounted for 97% of the total observed variation.

Soil pH and Extract pH

Relationships between soil pH and soil extract pH

There was a positive, significant relationship between soil pH and soil extract pH with 1.0 N NH_4Cl. This relationship is as follows

$$\text{Extract pH} = -0.01+0.88X \qquad [44]$$

where X is the soil pH. The regression equation accounted for 99% of the observed variation. Values for soil pH and pH of soil extracts with 1.0 N NH_4Cl are in Appendix Table 56.

CONCLUSIONS

From the experimental data and general observations certain conclusions were made:

1. Significant differences between soil clays from eastern Panama were found for CEC, pH-dependent CEC and specific surface. These differences were influenced primarily by the type of clay minerals present. Soil clay 1 from Patino exhibited a low CEC and specific surface and was found to be primarily halloysitic. With the exception of CEC for clay 4, the other clays exhibited high CEC and specific surface which was reflected in the large quantities of 2:1 phyllosilicates or their interstratified mixtures.
2. Amorphous materials removed by selective dissolution from the soil clays accounted for 24 to 53% of the original clay weight. Removal of these materials did not affect materially the CEC, pH-dependent CEC, and specific surfaces of the residual, more crystalline clay portion. These amorphous materials reacted like phyllosilicate relics and not allophane. This was further confirmed by the siliceous nature of the material removed by 0.5 N NaOH. The composition of these extracts was more siliceous, from SiO_2 Al_2O_3 mole ratios, than either aluminophane or halloysitic allophane. The development of such phyllosilicate relics as a major portion of the amorphous fraction was attributed to the tropical climate

combined with the relatively high amount of organic matter in these soils. Reactivity of the organic matter presumably resulted in chelation of Al and Fe freed from the clays in the weathering process and permitted illuviation of these elements.

3. A compound of variable composition not unlike Na cryolite was present after treatment of soil clays with acid NH_4F and the subsequent saturation of the exchange sites with Na. This compound was soluble in .0 N NH_4OAc at pH 7.0 and resulted in Na values in the extracts which made impracticable the calculations of the CEC of the Na-saturated clay after the F treatment.

4. A significant relationship was found between CEC determined at either pH 4.8 or 8.2 and the specific surface. The regression equations accounted for 87 and 83% of the observed variation, respectively. This was interpreted to mean that the specific surface available for glycol retention also measured the charged surfaces available for CEC.

5. Determination of the CEC on the whole soil, compared to the CEC of the dispersed clay fraction and organic matter content, does not adequately estimate the actual capacity of the clay for cation retention. This was demonstrated when the clay fraction alone, without considering organic matter, in most of these soils, accounted for a larger CEC than was measured for the whole soil. This suggests that many of the exchange sites in the whole soil were not available for saturation. This was probably due to cementation of the smaller soil

particles by organic matter, manganese oxides, and iron oxides. Such cementations were subsequently removed by oxidation with H_2O_2 and the dispersion process used for clay separation.

6 Data from X-ray diffraction studies indicated that the soil clays were poorly crystalline. Generally, a form of Z-axis limitation was demonstrated in the X-ray diffraction patterns by line broadening and plateaus in the region from 10- to 18-A spacing with rather small or no distinctive peaks. This was associated with a broad, intense peak at 3.5 A. The X-ray diffraction data revealed that the clay minerals found in these patterns were of the nature expected from values for CEC and specific surface. The single exception was soil clay 4 where the CEC was lower than anticipated from the minerals identified. Further examination of these patterns disclosed that chlorite and gibbsite were not present in these soil clays.

7 The DTA patterns showed the presence of a large endotherm in the low-temperature range. This was attributed to a combination of halloysite, 2:1 expandable phyllosilicates, and amorphous materials. The presence of halloysite in most of the clays was indicated from the slope of the endotherm in the range from 525 to 575C. The DTA patterns confirmed the absence of gibbsite noted in X-ray diffraction patterns.

8 Infrared analysis supported conclusions reached from the X-ray diffraction and DTA patterns. The absorption band at 3,450 cm^{-1} for water adsorbed to clay surfaces indicates

presence of halloysite and/or 2:1 expanding phyllosilicates. The absorption band at 910 cm^{-1} found for some of the soil clay fractions was attributed to Al-O-H bending, presumably from halloysite. Increases in the absorption band for Si-O vibrations were noted after treatment with citrate-dithionite and NaOH, these changes resulted from concentration of the more crystalline colloids.

9. As a compartment for effects of radioactive nuclides deposited after fallout, the soil would be expected to retain the radionuclides on the clay and organic matter surfaces. Penetration to only a shallow depth might be anticipated because of the high clay content and the high CEC of these soils. The migration of the nuclide through the soil profile depends largely on the tenacity with which the radionuclide would be adsorbed by the soil. Goldsmith (53) reported from a study of radionuclide retentions by six Panamanian clays, that the soil colloid portion represents a limitless reservoir for sorbing fallout of radiocations. The relatively large abundance of other cations which could displace the nuclide by a mass-action effect and to some extent the selective adsorption of nuclides by clays would contribute to the fate of the nuclide.

10. Extraction of the soil with 1.0 N NH_4Cl gave essentially the exchangeable ions and ions present in the soil solution. Data from these extracts indicate that these soils were quite fertile with high concentrations of nutrients essential for plant nutrition present in the soil compartment. The soil pH was only slightly acid, which enhances the availability

of p ant nutr ents, thus creating a suitab e medium for p ant growth Th s imp ies that any radionuc de present would be competing for plant uptake w th h gher concentrations of essential elements.

1. Few significant differences were found between loca ons for the concentration of essentia mineral elements in the soil and root and leaf tissue. This reflected the general high fertility of the soils in the area and ow expectation of differences in soil, root, and leaf-tissue compartments.

2. Use of 1.0 N NH_4Cl or 1.0 N HCl as a field test of root inorganic composit on m ght be justified where root ashing and extraction would be a ser ous delay in assessing radionuc ides as nutritional problems. Sequential root extractions showed the argest concentrat ons of root P, Mg, Fe, and Ca are found in the root-ash extract w th the except on of Ca in araguagrass where NH_4Cl extraction removed significantly larger quantities of these elements. The concentrat ons of root K, Mn, and Cu found in either the acid root extract or the root-ash extract were not significantly different. The single exception was araguagrass where the acid root extraction removed the largest amount of Cu. The largest concentrat on of Zn was removed with the acid extraction, wh e Sr was not found to be significant y h gher in any particular extract. Th s ndicates a low uptake of Sr by the spec es, wh ch were studied, growing in this area.

13 Significant relat onships were found between the soil extract and the sequentia root extracts and leaf-t ssue for several

elements. The relationships of most interest were the positive, significant relationships between the Sr by the mole ratio with other cations in the soil extract and the NH_4C and acid-root extract of helicon a. The Sr mole ratios in the soil extracts and those in the leaf tissue of helicon a are also significant. No significant relationships were found, however, between the concentration of Sr in the soil extract and the root extracts. Similar relationships were found for K by mole ratios with other cations in the soil extracts and those in the NH_4Cl root extracts of corn and jaraguagrass. Also significant relationships were found between the concentration of K in the soil extract and the root extract. This indicates the necessity of considering complimentary ions when predicting the uptake of Sr or K by certain plants.

14. Although 27 significant relationships were found, of the 112 cases considered, in general, the fit of the regression equation is not very good and accounts for small percentages of the observed variation and should not be used for prediction purposes. This is attributed to the variability of the soils and the general high fertility.

15. Estimation of the compartment magnitude for K, Ca, Sr, Mg, Fe, Mn, Cu, and Zn is provided from soil extracts, root composition, and leaf-tissue of the three species evaluated. Although, differences between species were not analyzed statistically, the trends were as follows: For the root compartment, helicona was the species highest in P, K, Ca, Sr, Mg, and Cu while jaraguagrass contained more Fe, Mn, and

Zn. For the leaf compartment, no data were available for corn, but heliconia contained larger concentrations of K, Ca, Fe, Mn, and Cu than araguagrass. The latter species contained more Sr, Mg, and Zn than did heliconia. The concentration of mineral elements present, in the root and leaf compartments, reveal the range to be expected under existing fertility conditions. From the concentrations of mineral elements present in the soil extract, radionuclides would not be expected to concentrate in abnormal quantities in the plant tissue except by selective absorption from the soil solution or by foliar uptake.

SUMMARY

This study was initiated to survey some of the most important chemical and physical properties of selected soils from eastern Panama. The samples were taken along portions of the area proposed as Route 7 for nuclear excavation of a sea-level canal. Retention of radioactive nuclides by the soil and availability of these nuclides for plant uptake are dependent on the negative charge density of both the minerals constituting the clay portion (< 2u) and the organic matter. The concentrations of essential elements available for plant growth in the soil compartment are related to those in the plant compartment by complexation associated with the process of root uptake of these elements. To evaluate and survey some of these relationships, samples were taken of soil and one or more adjacent plant species at selected locations.

Eight of the soils from eastern Panama were selected for detailed study of the clay fractions. These were considered to be representative of the major soil groups encountered in the field sampling. The clay fraction was separated and subjected to three selective dissolution treatments with the purpose of evaluating the nature of the amorphous and crystalline clay fractions. Triplicate samples were used, of each clay for each treatment, so that a statistical evaluation could be made for each set of data. Treatment of the soil clay with dithionite-citrate was followed first by hot 0.5 N NaOH and then by dithionite-citrate and in the final dissolution step with acid

NH_4F. The CEC and pH-dependent CEC by Na saturation and specific surface, by glycol retention were determined on the original clay and the residual clay after each sequential dissolution step. Also Si, Al, and Fe were determined in the extracts removed by each of these dissolution steps.

The CEC of the original clay before treatment at pH 4.8 ranged from 18.9 to 65.7 meq per 100 g while the pH-dependent CEC from pH 4.8 to 8.2 ranged from 2.3 to 7.5 meq per 100 g. Only small changes were noted in the CEC and pH-dependent CEC after each step of the treatments. The specific surface ranged from 2.3 to 473 M^2/g for the clay before treatment. No changes after treatment of these clays, were observed to be larger in magnitude than those found for a standard Wyoming bentonite subjected to the same treatments. Significant linear relationships were found between CEC values determined either at pH 4.8 or 8.2 and the values for specific surface. This was interpreted to mean that the specific surface available for glycol retention also measured the charged surfaces available for CEC.

These clays contained from 24 to 53% amorphous materials which were not allophane-like, but were probably phyllosilicate relics, as indicated by pH-dependent CEC and specific surface. The hypothesis that these amorphous materials were generally phyllosilicate relics or poorly crystalline minerals was further confirmed by the siliceous nature of the extracts after treatment with 0.5 N NaOH. The SiO_2 Al_2O_3 mole ratios for these extracts ranged from 5.92 to 1.73. The predominantly siliceous nature of the amorphous clay was attributed to the tropical climate combined with the relatively large amounts of organic matter in these soils which facilitated the weathering process.

X-ray diffraction, DTA, and infrared data were used to assist in the identification of the minerals in these clays. The X-ray diffraction patterns showed all the soil clays to be relatively, poorly crystalline. Those with the highest values for CEC and specific surface were composed primarily of montmorillonites, vermiculites and interstratified mixtures of these minerals. Smaller quantities of kaolinites were present. One soil clay which had a low CEC and specific surface was found to contain primarily kaolinites. Line broadening, plateaus between 10 and 18A with small differential peaks, and a dominant 3.5A peak observed in the X-ray diffraction patterns indicated 2:1 expanding lattice phyllosilicates, and amorphous materials. The shape of the endotherm found at high temperatures indicated that the kaolinites observed in the X-ray diffraction patterns were mostly halloysite. The absence of gibbsite was confirmed by the DTA analysis.

The infrared spectra showed a large absorption band at 3,450 cm^{-1} which is indicative of water adsorbed by the clay surface. This band was attributed to halloysite and/or 2:1 expanding lattice minerals. The presence of an absorption band at 910 cm^{-1} was attributed to Al-O-H bending and is presumed also to indicate the presence of halloysite.

The soil compartment which generally consisted of large quantities of clay and organic matter both of which have high CEC and specific

surfaces, appears to have a practically unlimited potential for nuclide retention. The soils were generally quite fertile. This was shown by the concentrations of K, Ca, Sr, Mg, Fe, Mn, Cu, and Zn found by extraction with 1.0 N NH_4Cl. Since the soils were also slightly acid these fertility conditions would suggest that radionuclides would not be preferentially concentrated in plants because of a toxicity or deficiency of essential elements or an imbalance between these elements. The large concentrations of available nutrients would also tend to exert a dilution effect on radionuclides deposited in the soil compartment.

The root and leaf tissue of the three plant species studied, corn, paraguagrass, and helicon a were not found to contain abnormally high concentrations of the elements analyzed. There were a total of 27 significant relationships found for the different elements between compartments. There were 20 significant relationships obtained between the soil and root compartments, while only seven significant relationships were found between the soil and leaf compartments. The regression equations for these relationships were generally not very good and accounted for little of the observed variation. Significant relationships were found for the Sr-mole ratios between the soil and root and the soil and leaf-tissue compartments. Also, similar relationships were found for K. This implies that the concentration of complementary ions present should be considered when uptake of Sr, K and when possibly radionuclides, which behave similarly, are to be estimated. The samples in the survey provided ranges for K, Ca, Sr, Mg, Fe, Mn, Cu, and Zn for the soil extract and the root and leaf tissue of the three species evaluated.

APPENDIX

Table 45.--Profile descriptions of soils used for clay mineral analysis

Location	Depth	Description
Profile #1		
Patino. Upland jaraguagrass pasture with 2 to 5% slope.	0 to 5 cm	Dark brown (7.5 YR 3/2) clay; coarse; strong crumb, fibrous roots present; pH 6.6
	15 to 45 cm	Reddish-yellow (5 YR 6/8) clay; fine crumb; friable, some concretions present, pH 6.2
	45 cm+	Dark reddish-brown (2.5 YR 3/4) clay, friable; mottling present, may be parent material.
Profile #2		
Yaviza. Alluvium jaraguagrass pasture. Approximately 100 meters from Rio Chico	0 to 15 cm	Very dark gray-brown (7.5 YR 3/2) silty clay, friable, fibrous roots present; pH 6.6
	15 to 100 cm	Brown to dark brown (10 YR 4/3) silty clay, friable, pH 6.0
Profile #3		
Santa Fe. Upland jaraguagrass pasture approximately 1/2 mile from O.I.C.S. Camp.	0 to 6 cm	Dark brown (7 YR 3/2) clay; medium crumb structure, friable, fibrous roots present, pH 6.6
	6 to 25 cm	Reddish-brown (5 YR 5/3) clay; subangular blocky, pH 4 5.

Tab e 45.--Continued

Location	Depth	Description
	25 cm+	Reddish-brown (5 YR 5/3), primary well-decomposed rock, some gray mottled fragments
Profile #4		
Trocha. Upland area northwest of Trocha, approximately five kilometers northeast of Santa Fe	0 to 15 cm	Very dark gray (10 YR 3/1) clay; subangular blocky structure, roots running horizontally in the top 10 cm, effervescence with HCl, pH 7.0
	15 to 30 cm	Very dark gray-brown (10 YR 3/2) clay, subangular blocky, firm; effervescence with HC ; pH 6.0.
	30 to 125 cm	Mottled red (7.5 YR 4/6), light olive brown (2/5 YR 5/6), clay, effervescence with HCl, pH 8.0.
Profile #5		
Rio Sabana. Upland approximately two kilometers from Rio Sabana n corn field near four-year-old successional p ots.	0 to 6 cm	Very dark gray (10 YR 3/1) clay; granular, fibrous roots present, free carbonates present, pH 8.0
	6 to 75 cm	Dark brown (10 YR 5/3) clay, subangular blocky, pH 7.0
	75 to 100 cm	Brown sh-yellow (10 YR 6/6)clay, subangular blocky to massive, yellowish-brown mottling, pH 4.7

Table 45.--Continued

Location	Depth	Description
Profi e #6		
Rio Lara. Alluvium, near two and one-half-year old successional samp ing plots.	0 to 30 cm	Dark brown (10 YR 4/3) to dark yellowish-brown (10 YR 4/4) clay, crumb structure, some mottling, pH 6 8.
	30 to 75 cm	Gray (10 YR 6/1) clay; subangular blocky, red mottling, 3 to 6 mm in diameter, pH 4.5
Profile #7		
Rio Chucunaque. Alluvium, approximately two kilometers up river from Yeviza on the south bank	0 to 28 cm	Dark brown (10 YR 4/3) silty clay; fine crumb structure, friab e, pH 6.2
	28 to 90 cm	Dark brown (10 YR 4/3) changing gradually to light brown (7.5 YR 6/4) silty clay; fine crumb; pH 5.6.
	90 to 150 cm	Brown (7.5 YR 6/4) clay loam, seepage encountered below 90 cm, reddish-brown mottling, pH 5.6.
Profile #8		
Rio Chico. Located near araguagrass field plots and approximately 300 meters from Rio Chico.	0 to 15 cm	Dark gray brown (10 YR 4/2) sandy loam; granu ar structure, friable, fibrous roots present, pH 6.6

Table 45--Continued

Location	Depth	Description
	15 to 25 cm	Very dark gray (10 YR 3/2) sandy clay loam, granular structure; friable, yellowish-brown mottling, pH 6.8.
	25 to 100 cm	Dark yellowish-brown (10 YR 4/4) clay loam; granular structure, dark gray mottling.

*Color by Munsell chart, pH by Truog kit, and surface texture by particle-size analysis.

Table 46.--CEC values of eight soil clays from eastern Panama and Wyoming bentonite at pH 4.8 and 8.2 before and after sequential dissolution treatments

	Treatments							
	Original		After dithionite-citrate		After 0.5 N NaOH		After acid NH_4F	
Clay	pH 4.8	pH 8.2	pH 4.8	pH 8.2	pH 4.8	pH 8.2	pH 4.8	pH 8.2
	meq/100 g							
	Rep. I							
1	29.0	38.6	30.5	43.2	35.2	43.7	42.9	42.9
2	62.1	68.1	66.0	80.7	72.2	84.3	74.1	55.8
3	59.8	67.2	58.2	78.9	86.8	94.8	70.7	62.6
4	18.9	21.8	18.4	28.7	24.9	28.5	71.9	71.9
5	64.3	74.3	75.0	69.8	77.1	67.0	64.4	61.6
6	48.8	59.5	43.4	49.5	49.7	60.1	53.0	57.9
7	56.8	61.6	40.4	73.0	46.2	54.8	67.6	53.5
8	67.6	83.5	84.3	114.8	92.4	108.7	48.2	56.2
Wy. bent.	59.	95.7	61.3	86.2	71.6	116.0	94.2	86.4
	Rep. II							
1	23.0	38.6	31.8	42.0	28.1	38.0	54.6	47.3
2	52.1	62.0	57.9	79.3	70.1	79.6	64.6	56.8
3	58.8	65.5	54.8	74.3	84.3	97.4	85.8	57.2
4	18.3	22.4	19.5	24.8	23.1	28.6	68.3	62.2
5	64.3	72.4	66.6	77.9	76.9	89.2	81.0	76.0
6	48.2	56.1	40.7	49.5	48.8	56.3	62.2	56.5
7	52.6	62.8	53.7	75.9	53.6	62.0	60.6	60.6
8	64.4	85.6	69.8	105.1	72.9	89.7	41.0	41.0
Wy. bent	59.1	98.5	57.5	86.3	85.0	06.3	85.6	105.5
	Rep. III							
1	29.6	37.6	31.0	40.6	25.7	34.2	55.3	44.2
2	59.0	68.1	57.3	79.3	63.3	79.6	61.3	47.9
3	63.0	68.2	61.9	80.8	79.8	96.0	73.7	67.7
4	19.6	23.0	21.1	26.6	24.9	28.5	67.3	58.6
5	58.8	72.4	66.	88.8	78.0	88.5	89.5	71.6
6	48.2	60.9	43.4	48.2	54.2	60.0	68.0	63.4
7	56.8	62.8	67.9	90.2	68.5	77.7	92.7	56.2
8	65.1	80.5	87.9	111.5	83.2	92.2	41.4	48.5
Wy. bent.	60.2	90.3	61.1	86.9	85.0	94.2	110.6	94.2

Table 47.--CEC, F, and Al content found in 1.0 N NH_4OAc extract, following sequential Na saturation of clays, after treatment with acid NH_4F.

No.	Clay	Rinse after treatment	Saturation pH	CEC	F	Al
				--meq/100 g---		ppm
			First saturation			
X_1	Wy. bent	NH_4Cl	4.8	212.0	175.0	6,000
X_2	Wy. bent.	NH_4Cl	4.8	195.0	127.0	6,350
X_3	Wy. bent.	NH_4Cl	8.2	167.0	41.8	0
X_4	Wy. bent.	NH_4Cl	8.2	157.0	47.4	0
X_5	Wy. bent.	H_2O	4.8	192.0	141.0	5,360
X_6	Wy bent.	H_2O	4.8	203.0	154.0	5,260
X_7	Wy. bent.	H_2O	8.2	166.0	71.0	0
X_8	Wy. bent.	H_2O	8.2	173.0	62.2	0
1	Patino	NH_4Cl	8.2	242.0	114.0	24,500
1A	Patino	NH_4Cl	8.2	263.0	148.0	14,900
2	Yeviza	NH_4Cl	8.2	157.0	54.8	12,800
2A	Yeviza	NH_4Cl	8.2	186.0	85 5	10,500
3	Santa Fe	NH_4Cl	8.2	162.0	46.2	6,900
3A	Santa Fe	NH_4Cl	8.2	292.0	165.0	19,100
4	Trocha	NH_4Cl	8.2	253.0	138.0	16,900
4A	Trocha	NH_4Cl	8.2	257.0	135.0	6,300
5	Rio Sabana	NH_4Cl	8.2	230.0	82.2	9,370
5A	Rio Sabana	NH_4Cl	8.2	175.0	60.5	8,730
6	Rio Lara	NH_4Cl	8.2	166.0	58.5	6,120
6A	Rio Lara	NH_4Cl	8.2	168.0	38.6	6,460
7	Rio Chucunaque	NH_4Cl	8.2	224.0	112.0	6,700
7A	Rio Chucunaque	NH_4Cl	8.2	222.0	98.1	14,900
8	Rio Chico	NH_4Cl	8.2	193.0	71.2	3,100
8A	Rio Chico	NH_4Cl	8.2	185.0	77.0	1,900
9	Wy. bent.	NH_4Cl	8.2	168.0	24.6	2,630
9A	Wy. bent.	NH_4Cl	8.2	167.0	25.7	2,860
			Second saturation			
X_1	Wy. bent.	H_2O	8.2	108.0	2.6	0.0
X_2	Wy. bent.	H_2O	8.2	110.0	6.3	0.0
X_3	Wy. bent.	H_2O	4.8	128.0	3.6	0.0
X_4	Wy. bent.	H_2O	4.8	123.0	25.2	0.0
X_5	Wy. bent.	H_2O	8.2	115.0	9.3	0.0
X_6	Wy. bent.	H_2O	8.2	113.0	4.6	0.0
X_7	Wy. bent.	H_2O	4.8	120.0	4.6	0.0
X_8	Wy. bent.	H_2O	4.8	121.0	3.9	0.0

Table 47.--Continued

No.	Clay	Rinse after treatment	Saturation pH	CEC	F	Al
				--meq/100 g --		ppm
			Second saturation (Cont d)			
1	Patino	H_2O	4.8	75.2	12.0	0.0
1A	Patino	H_2O	4.8	60.3	7.8	0.0
2	Yeviza	H_2O	4.8	72.0	0.9	0.0
2A	Yeviza	H_2O	4.8	72.1	1.5	0.0
3	Santa Fe	H_2O	4.8	110.0	50.0	0.0
3A	Santa Fe	H_2O	4.8	78.0	0.5	0.0
4	Trocha	H_2O	4.8	68.2	0.5	0.0
4A	Trocha	H_2O	4.8	7 .0	0 4	0.0
5	Rio Sabana	H_2O	4.8	115.0	3.5	0.0
5A	Rio Sabana	H_2O	4.8	89.7	3.0	0.0
6	Rio Lara	H_2O	4.8	86.7	4.0	0.0
6A	Rio Lara	H_2O	4.8	101.0	3.0	0.0
7	Rio Chucunaque	H_2O	4.8	64.8	0.3	0.0
7A	Rio Chucunaque	H_2O	4.8	64.8	0.6	0.0
8	Rio Chico	H_2O	4.8	64.3	1.4	0.0
8A	Rio Chico	H_2O	4.8	65.3	1.3	0.0
9	Wy. bent.	H_2O	4.8	1 1.0	0.4	0 0
9A	Wy. bent.	H_2O	4.8	102.0	0.6	0.0
			Third saturation			
X_3	Wy. bent.	H_2O	8.2	54.8	0.2	0.0
X_4	Wy. bent.	H_2O	8.2	112.3	9.4	0.0
X_7	Wy. bent.	H_2O	8.2	117.5	0.2	0.0
X_8	Wy. bent.	H_2O	8.2	120.5	0.1	0.0

Table 48.--Specific surface values of eight soil clays from eastern Panama and wyoming bentonite before and after sequential dissolution treatments

Sample No.	Treatments							
	Original		After dithionite-citrate		After 0.5 N NaOH		After acid NH_4F	
	Rep.		Rep.		Rep.		Rep.	
	1	2	1	2	1	2	1	2
	m^2/g							
1	218	207	158	185	225	245	09	129
2	342	340	256	184	376	342	198	232
3	366	355	386	392	393	411	157	108
4	409	419	402	384	312	246	279	148
5	467	478	488	413	347	412	299	285
6	387	366	502	454	391	367	344	356
7	371	356	206	178	346	257	99	130
8	263	272	290	327	228	191	104	94
Wy. bent.	627	767	454	511	614	603	455	513

Table 49.--Effect of sequential dissolution on the composition of 'amorphous' mater al removed by sequential dissolution steps

Clay	Composition of materials removed							
	Si		Al		Fe		Mg	
	Rep.		Rep.		Rep.		Rep.	
	1	2	1	2	1	2	1	2
	mg/g							
	Na dithionite-citrate							
1	2.63	2.75	12.38	13.00	117.75	119.13	-	-
2	3.88	3.38	11.25	9.63	60.63	80.13	-	-
3	1.88	4.50	23.38	22.60	75.13	44.90	-	-
4	4.50	4.50	7.63	9.38	73.50	96.75	-	-
5	6.00	5.50	7.63	6.75	50.50	47.25	-	-
6	4.00	3.50	11.75	9.88	103.88	89.25	-	-
7	5.75	5.25	8 75	10.00	84.38	98.25	-	-
8	4.13	4.75	11.00	11.75	87.50	96.63		
Wy bent.	1.88	2.13	0.88	0.88	5.38	4.38	-	-
	0.5 N NaOH							
1	156.6	162.2	47.1	50.3	0.99	0.97	-	-
2	151.1	166.2	39.9	39.5	1.25	1.25	-	-
3	80.1	101.6	29.0	32.4	0.29	1.41	-	-
4	90.2	131.3	17.5	26.3	0.92	1.25	-	-
5	71.8	101.1	21.6	16.8	1.38	2.47	-	-
6	79.0	86.7	12.6	14.4	0.79	0.79	-	-
7	165.1	182.8	39.6	47.5	1.72	1.97	-	-
8	117.1	126.1	35.8	42.9	1.38	1.46	-	-
Wy. bent.	40.3	36.5	4.8	3.7	1.06	0.42	-	-
	Na dithionite-citrate after 0.5 N NaOH							
1	7.6	8.4	2.4	2.6	8.3	7.4	-	-
2	10.9	11.3	2.6	2.4	13.6	14.8	-	-
3	8.4	19.5	3.8	7.0	0.5	4.5	-	-
4	8.9	13.8	1.7	2.0	4.6	8.4	-	-
5	7.8	10.1	1.4	2.7	2.8	5.1	-	-
6	10.2	6.9	1.8	1.2	4.2	1.4	-	-
7	13.9	14.7	2.9	3.3	12.3	17.0	-	-
8	13.2	12.9	2.8	2.8	12.7	11.1	-	-
Wy. bent.	3.3	3.8	0.3	0.3	0.1	0.1	-	-

Table 49.--Continued

Clay	Composition of materials removed							
	Si		Al		Fe		Mg	
	Rep.		Rep.		Rep.		Rep.	
	1	2	1	2	1	2	1	2
	mg/g							
	Acid NH_4F							
	17.8	18.2	3.2	3.1	5.7	4.7	0.9	0.9
2	30.4	29.7	3.3	.6	9.8	7.4	3.3	3.6
3	10.1	21.5	0.5	2.1	3.3	2.5	0.3	0.7
4	18.0	24.4	.5	1.5	3.2	3.4	.1	.5
5	27.0	30.6	0.7	0.5	29.1	16.8	.2	.0
6	27.	22.9	0.7	0.7	13.8	1.3	.2	.0
7	34.9	36.8	2.8	2.9	20.5	22.5	3.7	4.2
8	26.9	26.6	2.6	2.8	15.4	17.5	2.5	2.4
Wy. bent.	5.6	7.0	0.3	0.3	0.2	0.1	0.1	0.3

Table 50.--Loss of amorphous material after sequent a d sso ution treatment when a sma l sample weight was employed

Clay	Treatments			
	After dithionite-citrate	After 0.5 N NaOH	After acid NH_4F	comb.ned total
			--%--	
1	27.69	24.00	27.96	79.65
2	32.10	16.54	16.64	65.28
3	31.79	25.90	9.55	67.24
4	28.79	27.87	33.14	89.80
5	22.50	2 .07	21.01	64.60
6	13.92	25.14	20.46	59.53
7	42.39	15.20	20.68	78.29
8	38.18	16.54	14.36	69.09
Wy. bent.	8.70	19.23	8.75	36.69

Table 51. -Effect of sequential dissolution treatment on thermogravimetric analysis

Clay	Water loss at 105-200C		
	Before dissolution	After dissolution	
		Rep. 1	Rep. 2
	---------- wt. % ----------		
1	1.57	1.25	1.77
2	1.62	1.99	3.01
3	1.11	1.24	1.31
4	1.95	2.71	1.46
5	0.96	1.45	1.20
6	0.97	1.66	1.13
7	1.26	2.11	1.66
8	2.58	1.27	1.24
Wy. bent.	1.[illegible]	0.89	0.75

Table 52 The d/n spacing of crystalline minerals recognized from X-ray diffraction patterns of soil clays from eastern Panama

Sample preparation	Treatments: Original	After dithionite-citrate	After 0.5 N NaOH	After acid NH_4F
	A spacing			
	1- Patino			
Mg saturation and glycerol solvation	23.23-19.9, 16.97-10.15, 7.30, 4.43*, 4.16, 4.07, 3.70-3.55	36.77 28.47, 25.22-16.05, 11.62-8.18, 8.03, 7.68, 7.30*, 4.43, 4.2, 3.65-3.54	7.36, 4.07 3.61-3.53	22.63, 7.13 4.28, 4.05 3.55
K saturation	7.43*, 4.48-4.09, 3.6	44.3-33.95, 7.49, 4.52-4.09, 3.60*	7.36*, 4.07* 3.61 3.53	22.63, 7.13 4.28, 4.05*, 3.55
K saturation and heat treated	No peaks	No peaks	3.37	4.01*
	2- Yeviza			
Mg saturation and glycerol solvation	35.30, 25.22-18.39, 3.65	22.07-19.9, 6.80, 3.47	44.13-31.52, 24.52-17.65*, 17.65-14.0, 9.20, 7.62, 3.58*, 3.34	22.07-16.97*, 7.62, 4.54-3.89, 3.61*, 3.37
K saturation	44.13-29.42, 18.39-12.98*, 8.41-6.96, 4.18, 3.55*, 3.49-3.33	44.3-29.42*, 23.23-19.61, 19.61-11.04, 7.36, 4.48, 3.54*	44.13-29.42, 25.22-18.39, 14.71*, 7.24, 3.58*, 3.36	23.23-20.53, 7.49, 4.28, 3.57*, 3.37
K saturation and heat treated	3.36	3.36	10.3*, 5.03, 3.34*	23.23-19.61, 17.65-10.04*, 3.55, 3.36*

Tab e 52.- Continued

Sample preparation	Treatments: Original	After dithionite-citrate	After 0.5 N NaOH	After acid NH_4F
	A spacing			
	3- Santa Fe			
Mg saturation and glycerol solvation	21.53, 7.36, 4.54-4.22, 3.60*, 3.37	No data	23.23-15.45, 9.20, 7.49*, 4.48, 3.58*, 3.38	23.23-15.45, 7.43*, 4.48, 3.61*, 3.38
K saturation	44.13-32.69, 25.22-7.65 7.30, 4.52-4.03, 3.55*, 3.34	44.13-29.42, 23.23-9.99, 19.19-11.93, 7.36, 4.57-4.05, 3.57*, 3.38, 3.33	44.13-32.69, 22.63-12.61, 7.30*, 4.50, 3.43*, 3.36	44.13-32.69, 25.22-1.77, 7.43*, 4.54, 3.58*, 3.38
K saturation and heat treated	No peaks	No peaks	17.65-9.82*, 4.89, 3.33*	17.65-9.30*, 4.92*, 3.38*
	4- Trocha			
Mg saturation and glycerol solvation	No data	25.22-2.02, 20.0-18.39, 18.0-14.47, 8.41-7.24,* 3.65, 3.60	30.44-6.60, 7.36, 4.45, 3.58*, 3.36	7.24, 4.50-3.86, 3.33
K saturation	4.71-3.86, 3.55	44.13-29.42*, 23.23-11.0, 7.43, 3.61-3.53*	44.3-29.42*, 23.85-11.0*, 7.49-7.30, 3.58*, 3.36	7.43-7.07, 4.52-4.00, 3.57, 3.36*
K saturation and heat treated	No peaks	No peaks	12.6-10.2*, 5.09, 3.37*	12.44-9.01, 3.34

Table 52.--Continued

Sample preparation	Treatments: Original	After dithionite-citrate	After 0.5 N NaOH	After acid NH_4F
	----------A spacing----------			
	5- Rio Sabana			
Mg saturation and glycerol solvation	33.95, 26.75-18.39*, 8.39-11.62, 9.40, 7.55*, 4.54*, 3.67-3.51*, 3.38*	44.13-29.44, 25.22-6.05*, 9.20, 4.66-4.03, 3.67-3.53	No peaks	23.85-17.65, 11.0-10.0, 9.40*, 4.59-3.64-3.58*, 3.55*, 3.37
K saturation	44.13-32.69, 25.22-9.0, 7.30, 4.50-4.18, 3.65-3.51, 3.36	44.13-32.69, 24.52-9.01*, 7.43, 4.43, 3.55*, 3.36	44.13-32.69, 23.23-16.35*, 16.35-11.04*, 9.11, 7.30, 4.54-4.43, 4.26, 3.58-3.51*, 3.36*	25.22-8.41*, 7.36, 4.48, 3.55*, 3.37
K saturation and heat treated	7.65-9.20, 3.47, 3.41	7.65-9.1[illegible], 3.37	17.65-8.75, 4.74-4.22, 3.36-3.17	22.07-8.83*, 4.59, 3.36*
	6- Rio Lara			
Mg saturation and glycerol solvation	7.75, 4.66-4.03, 3.70-3.55, 3.37	44.13-29.42, 22.07-17.65*, 9.20, 7.43, 4.61-4.26, 3.63-3.55*, 3.37*	44.13-29.42, 22.07-17.65*, 9.20*, 7.36*, 4.52, 3.58*, 3.36*	23.85-15.49*, 10.5-8.92, 7.49-7.24*, 4.54, 3.6-3.57*, 3.37*, 3.02
K saturation	44.1-16.9*, 16.9-9.0, 7.30, 4.66-4.22, 3.63-3.49*, 3.37	44.1-16.9, 16.9-8.83, 7.30, 4.43, 3.58-3.53 3.37	44.1-16.9, 25.22-11.04, 7.43, 4.92-4.48, 3.63-3.50*, 3.38	44.1-6.9, 25.22-8.58*, 7.43, 5.09-4.30, 3.58*, 3.37*
K saturation and heat treated	12.61-9.81, 5.18-4.66, 3.36*	No peaks	16.97-9.50, 4.81, 3.37*	17.65-10.27*, 5.12-4.87, 3.38*

Table 52.--Continued

Sample preparation	Treatments			
	Original	After dithionite-citrate	After 0.5 N NaOH	After acid NH_4F
	A spacing			
	7- Rio Chucunaque			
Mg saturation and glycerol solvation	23.8-18.3*, 8.0-7.2, 4.57, 3.63*, 3.37	23.23- 5.7, 7.6, 3.61*	8.3*, 9.2, 8.11-7.36, 7.13, 3.57*, 3.34	8 0-7.4, 3.65*
K saturation	4 43, 3.55	44. -32.6, 17.65-14.17, 7.30, 3.57*	7 49, 3.60*, 3.38	4.54-4 12
K saturation and heat treated	17.65-11.04, 3.36*	No peaks	3.39*	11.6-10.9, 4.66, 3.45*
	8- Rio Chico			
Mg saturation and glycerol solvation	23.8= 2.8, 3.58*, 3.54, 3.34	4.32, 3.57* 3.36	32.69-14.0, 7.89-7.13, 3.58*, 3.36	17.65-14.47, 8.18-7.18, 3.60*, 3.37
K saturation	44.13-32.69, 24.52-20.65, 4.30, 3.55*, 3.48	44.13 32.69, 24 52-20 65, 4.43, 3.55*	7.6-9.8 , 8 49-7 13, 3.60*, 3.54, 3.38	7.55-7.0, 4 37, 3.63-3.47, 3.34
K saturation and heat treated	No peaks	11.47-10.00*, 3.37*	3.43-3.31*	10.0*, 3.53*

*Highest relative intensity of peaks in pattern.

Table 53.--Locations representing three principal soil groups from which soil and adjacent root and tissue samples were taken

Location				
No.	Name	Sites	Soil	Plant
1	Yaviza	26	Alluvium	Jaraguagrass
2	Yaviza	2	Alluvium	Heliconia
3	Trocha	9	Upland non-latosol	Heliconia
4	Santa Fe	2	Upland non-latosol	Heliconia
4	Santa Fe	26	Upland non-latosol	Jaraguagrass
5	Rio Lara	5	Alluvium	Corn
5	Rio Lara	4	Alluvium	Heliconia
6	Nuno	2	Upland non-latosol	Corn
6	Nuno	2	Upland non-latosol	Heliconia
7	Rio Sabana	4	Alluvium	Corn
8	Santa Fe	3	Upland non-latosol	Corn
9	Santa Fe	6	Upland non-latosol	Corn
11	Chucunaque	2	Alluvium	Corn
12	Rio Grande	4	Alluvium	Corn
13	Pinogana	2	Alluvium	Corn
16	Patino	26	Upland latosol	Jaraguagrass

Table 54.--Concentration of elements in soil, root extracts and leaf tissue of corn, heliconia and paragrass from all locations sampled in eastern Panama

Extract	No. of sites	Mean	Maximum	Minimum	Standard deviation
			ppm		
			Corn, P		
Soil extract	28	0.0	0.0	0.0	0.0
Root extracts					
(I)	27	0.0	0.0	0.0	0.0
(II)	27	40.4	206.0	0.0	46.9
(III)	26	54.2	90.8	26.6	18.6
(IV)	26	84.4	193.5	33.8	37.0
			Corn, K		
Soil extract	28	493	1,226	106	315
Root extracts					
(I)	27	64.0	157	12.0	39.0
(II)	27	575	1,295	0.0	458
(III)	26	492	1,450	70.0	352
(IV)	26	1,169	3,088	158	836
			Corn, Ca		
Soil extract	28	4,830	10,100	940.0	1,830
Root extracts					
(I)	27	130	550	40.0	130
(II)	27	280	1,640	69.0	340
(III)	26	400	6,100	80.0	1,140
(IV)	26	800	7,750	220	1,460

Table 54,--Continued

Extract	No. of sites	Mean	Maximum	Minimum	Standard deviation
			ppm		
			Corn, Sr		
Soil extract	28	32.2	75.6	3.9	16.2
Root extracts					
(I)	27	1.8	6.7	0.0	1.4
(II)	27	1.1	8.7	0.0	2.0
(III)	26	1.6	17.4	0.0	3.2
(IV)	26	4.1	32.8	1.3	5.8
			Corn, Mg		
Soil extract	28	653	1,150	196	249
Root extracts					
(I)	27	21.1	70.5	7.2	14.9
(II)	27	34.5	84.0	15.3	16.2
(III)	26	107	251	8.0	48.0
(IV)	26	170	399	93.0	70.0
			Corn, Fe		
Soil extract	28	1.09	11.50	0.00	2.05
Root extracts					
(I)	27	4.3	23.5	0.0	6.4
(II)	27	9.0	48.0	0.0	10.2
(III)	26	176	498	20.0	119
(IV)	26	189	566	44.0	130

Tab e 54.--Continued

Extract	No. of sites	Mean	Maximum	Minimum	Standard deviation
			ppm		
			Corn, Mn		
Sol extract	28	0.46	4.20	0.10	0.79
Root extracts					
(I)	27	0.87	13.40	0.00	2.50
(II)	27	4.2	19.7	0.2	4.5
(III)	26	4.3	17.3	0.2	3.8
(IV)	[illegible]	9.3	40.0	2	9 4
			Corn Cu		
Soil extract	28	0.18	0.70	0.00	0.14
Root extracts					
(I)	27	0.64	4.70	0.00	1.09
(II)	27	3.8	12 4	0.5	3.0
(III)	26	3.6	15.4	0.3	2.7
(IV)	26	7.8	32.5	2.4	5.9
			Corn, Zn		
Soil extract	28	0.49	1.60	0.10	0.36
Root extracts					
(I)	27	4.5	13.4	2.0	2.7
(II)	27	6.0	25.0	1.6	5 2
(III)	26	2 6	23.4	0.0	4 5
(IV)	26	13.3	48.8	5.4	10.3

Table 54.--Continued

Extract	No. of sites	Mean	Maximum	Minimum	Standard deviation
			ppm		
			Heliconia, P		
Soil extract	21	0.0	0.0	0.0	0.0
Root extracts					
(I)	21	0.0	0.0	0.0	0.0
(II)	21	41.0	154	5.0	37.0
(III)	21	69.0	163	7.0	45.0
(IV)	21	103	249	21.0	69.0
			Heliconia, K		
Soil extract	21	192	542	54.0	120
Root extracts					
(I)	21	85.0	198	12.0	47.0
(II)	21	993	2,630	192	549
(III)	21	711	2,260	84	510
(IV)	21	1,740	3,470	222	787
Leaf tissue	18	21,200	29,500	15,600	3,190
			Heliconia, Ca		
Soil extract	21	5,220	8,090	1,970	1,440
Root extracts					
(I)	21	113	253	50.0	60.0
(II)	21	449	965	178	188
(III)	21	1,050	2,920	87.0	831
(IV)	21	1,610	3,810	463	935
Leaf tissue	18	5,340	7,750	3,900	856

Table 54.--Continued

Extract	No. of sites	Mean	Maximum	Minimum	Standard deviation
		ppm			
		Heliconia, Sr			
Soil extract	21	27.5	56.2	17.4	9.6
Root extracts					
(I)	21	1.6	2.5	0.0	0.8
(II)	21	2.6	5.4	0.8	1.2
(III)	21	3.6	12.0	0.8	2.6
(IV)	21	7.8	18.0	2.6	3.5
Leaf tissue	18	23.8	109.5	7.3	22.1
		Heliconia, Mg			
Soil extract	21	821	1,820	433	287
Root extracts					
(I)	21	35.0	74.0	11.0	15.0
(II)	21	153	250	55.0	56.0
(III)	21	464	955	113	236
(IV)	21	652	1,170	224	248
Leaf tissue	18	3,790	6,330	3,000	895
		Heliconia, Fe			
Soil extract	21	1.3	4.1	0.1	1.1
Root extracts					
(I)	21	5.2	21.3	0.2	6.4
(II)	21	16.2	99.0	0.0	21.7
(III)	21	139	290.0	41.3	65.5
(IV)	21	156	318	45.0	71.0
Leaf tissue	18	193	1,250	36.8	269

Table 54.--Continued

Extract	No. of sites	Mean	Maximum	Minimum	Standard deviation
		ppm			
		Heliconia, Mn			
Soil extract	21	0.81	2.40	0.10	0.72
Root extracts					
(I)	21	0.51	1.10	0.00	0.29
(II)	21	4.1	9.4	1.4	2.0
(III)	21	6.6	29.0	1.3	6.6
(IV)	21	11.3	33.5	4.4	7.3
Leaf tissue	18	205	487.0	61.0	109
		Heliconia, Cu			
Soil extract	21	0.48	2.40	0.10	0.53
Root extracts					
(I)	21	1.1	2.7	0.0	0.7
(II)	21	5.8	13.4	2.3	2.6
(III)	21	7.0	18.2	2.2	3.6
(IV)	21	13.8	23.6	5.3	4.9
Leaf tissue	18	22.5	52.8	13.8	8.2
		Heliconia, Zn			
Soil extract	21	2.2	10.3	0.30	2.5
Root extracts					
(I)	21	5.8	29.1	1.8	6.7
(II)	21	8.0	24.4	3.2	4.2
(III)	21	3.1	7.0	0.0	2.0
(IV)	21	17.0	37.3	9.8	7.9
Leaf tissue	18	38.0	55.0	26.0	8.3

Table 54.--Continued

Extract	No. of sites	Mean	Maximum	Minimum	Standard deviation
			ppm		
			Jaraguagrass, P		
Soil extract	79	0.0	0.0	0.0	0.0
Root extracts					
(I)	73	0.0	0.0	0.0	0.0
(II)	70	17.0	98.0	0.0	13.9
(III)	73	48.7	94.8	4.6	14.6
(IV)	70	66.3	176	34.9	24.2
			Jaraguagrass, K		
Soil extract	79	422	1,380	56.4	282
Root extracts					
(I)	73	24.1	93.0	2.0	16.6
(II)	72	226	540	20.3	121
(III)	73	426	957	76.0	136
(IV)	72	681	1,220	181	219
Leaf tissue	72	17,800	25,000	12,500	2,610
			Jaraguagrass, Ca		
Soil extract	77	3,910	6,830	2,090	1,020
Root extracts					
(I)	72	152	248	72.0	39.0
(II)	73	133	494	43.0	76.0
(III)	73	104	365	43.0	57.0
(IV)	72	388	815	191	114
Leaf tissue	72	4,530	11,400	3,000	976

Table 54.--Continued

Extract	No. of sites	Mean	Maximum	Minimum	Standard deviation
			ppm		
			Paraquagrass, Sr		
Soil extract	79	25.7	48.7	14.3	7.1
Root extracts					
(I)	72	1.3	4.6	0.0	0.9
(II)	73	0.28	1.6	0.0	0.33
(III)	73	0.77	2.2	0.0	0.53
(IV)	72	2.4	5.8	0.7	1.1
Leaf tissue	72	34.2	89.8	17.8	10.7
			Paraquagrass, Mg		
Soil extract	78	956	1,760	368	396
Root extracts					
(I)	72	31.5	60.5	15.5	7.3
(II)	73	26.3	72.0	13.0	10.6
(III)	73	139	630	52.0	97.0
(IV)	72	196	739	99.0	105
Leaf tissue	72	1,720	2,580	1,110	355
			Paraquagrass, Fe		
Soil extract	78	0.87	10.9	0.0	1.80
Root extracts					
(I)	72	2.3	41.0	0.0	6.0
(II)	72	65.0	369	0.0	64.0
(III)	73	358	2,190	76.0	304
(IV)	71	426	2,310	86.0	321
Leaf tissue	72	112	515	25.0	91.0

Table 54.--Continued

Extract	No. of sites	Mean	Maximum	Minimum	Standard deviation
			ppm		
			Jaraguagrass, Mn		
Soil extract	78	0.68	6.70	0.10	1.33
Root extracts					
(I)	72	0.32	6.20	0.0	0.75
(II)	72	6.7	19.0	9.0	4.4
(III)	73	5.9	23.6	0.9	4.7
(IV)	71	12.9	36.4	2.1	8.5
Leaf tissue	72	26.5	101	7.3	13.0
			Jaraguagrass, Cu		
Soil extract	78	0.05	0.4	0.00	0.07
Root extracts					
(I)	72	0.34	5.5	0.00	0.75
(II)	72	0.81	7.5	0.00	1.04
(III)	73	2.70	5.9	1.70	0.98
(IV)	71	3.90	16.3	1.80	2.10
Leaf tissue	72	17.8	42.3	4.8	8.3
			Jaraguagrass, Zn		
Soil extract	78	0.84	5.8	0.00	1.07
Root extracts					
(I)	72	6.1	59.0	0.30	6.7
(II)	72	9.6	28.0	0.50	4.4
(III)	73	5.7	198	0.0	24.0
(IV)	71	21.6	222	4.6	26.4
Leaf tissue	72	62.6	325	1.0	68.3

Table 55. Estimation of contamination in root extract on analysis from soil particles

Root location no.	Element analyzed			Estimated contamination	Mole ratio Mg+Ca.Fe
	Mg	Ca	Fe		
	μmoles x 10^{-4}/100 g			%	
1	0.0	0.0	5.0	0.70	-
1	0.0	0.0	17.9	2.49	-
4	33.4	0.0	51.6	11.84	-
4	16.5	0.0	53.9	9.80	-
5	0.0	0.0	9.5	1.32	-
8	0.0	0.0	74.7	10.40	-
9	0.0	0.0	28.2	3.92	-
13	0.0	0.0	39.6	5.51	-
16	0.0	0.0	82.4	11.47	
16	0.0	0.0	136.6	19.03	-
Average	5.0	0.0	49.9	7.65	0.10
Soil location no					
3	230.3	57.4	521.0	-	-
4	121.7	98.8	485.2	-	-
4	93.8	79.6	282.5	-	-
5	497.5	63.9	338.4	-	-
Average	235.8	74.9	406.8	-	0.76

Table 56.--Soil pH and pH of 1.0 N NH_4Cl extract from 11 locations in eastern Panama

Location	Soil reaction 1:2 H_2O	Soil reaction Soil extract 1.0 N NH_4Cl	Location	Soil reaction 1 2 H_2O	Soil reaction Soil extract 1.0 N NH_4Cl
	pH			pH	
2	6.1	-	5	6.6	-
(Yaviza)	5.9	-	(Río Lara)	6.1	-
				7.4	
3	7 4			7.4	-
(Trocha)	6.8	-			
	6.6	-	6	7.4	-
	6.0	-	(Nuno)	7 4	-
	6 4			7.3	-
	6.1			7.2	
	5 8	-			
	5.6	-	7	6.2	-
			(Río Sabana)	7.2	-
4	5.1	-		7 2	-
(Santa Fe)	5.6	4.7		6.6	6.0
	6.0	5.0		7.0	6.5
	7	6 6			
	6.4	5.6	8	7.4	
	7.4	6.8	(Santa Fe)	6.8	-
	7.	6 6		6.4	-
	6.8	6.5			
	6.9	6.4	9	7.0	6.8
	6.4	6.0	(Santa Fe)	5.1	6.6
	6.2	5.6		6.5	5.5
	5.8	5.2		7.4	6.8
	6.4	6.2			
	6.6	6.5	11	6.5	5.5
	6.7	6.7	(Chucunaque)	6.8	5.7
	6.3	5.8			
	6.9	6.8	12	7.8	6.8
	5.2	4.8	(R o Grande)	7.5	6 8
	5.7			7.0	5.6
	5.3	4.8		6.8	5 6
	6.2	5.6			
	7.1	6.7	3	7.2	6 0
	5.8	4.2	(Pinogana)	7.0	5 9
	7.1	6.4			
	7.0	6.4			
	5 6	4.5			

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BIOGRAPHICAL SKETCH

Raymond B. Reneau, Jr., was born September 11, 1941, at Burkesville, Kentucky. He received his elementary and secondary education in Clinton county school systems. In June, 1964, he was awarded the Bachelor of Science with a major in Agriculture from Berea College. In September, 1964, he enrolled in the Graduate School of the University of Kentucky. He worked as a graduate assistant in the Department of Agronomy until June, 1966, when he received the degree of Master of Science with a major in Agronomy. He entered the Graduate School of the University of Florida in 1966, as a research assistant, during which time he worked toward his degree of Doctor of Philosophy.

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This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of that committee. It was submitted to the Dean of the College of Agriculture and to the Graduate Council, and was approved as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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